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Influence of air ions on the carbon dioxide output of the European corn borer, *Ostrinia nubilalis*

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Influence of air ions on the carbon dioxide output of the
European corn borer, Ostrinia nubilalis

by

Leo Harold Soderholm

A Dissertation Submitted to the
Graduate Faculty in Partial Fulfillment of
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LIST OF SYMBOLS AND ABBREVIATIONS

A	Air volume (cc/sec)
α	Recombination coefficient
amu	Atomic mass unit
ASCII	American standard code for information interchange
BCD	Binary coded decimal
c	Velocity of light in free space
cc	Cubic centimeter
C	Centigrade
cm	Centimeter
CPS	Conversational programing system
c.s.t.	Central standard time
D	Diameter
DAS	Data acquisition system
DC	Direct current
dps	Disintegrations per second
E	Field strength (volts/cm)
ev	Electron volt
F	Fahrenheit
gm	Gram
h	Electron attachment coefficient
hr	Hour
Hz	Hertz (cycles/sec)
i	ion pairs
I	Current in amperes

IDVM	Integrating digital voltmeter
Io	Ion output (ions/cm ³ /sec)
IP	Ion pairs
IR	Infrared
k	Ion mobility constant
km	Kilometers
Kev	Thousand electron volts
λ	Lamda (10 ⁻⁶ liters)
L	Length
M	Mobility (cm ² /volt-sec)
mc	Millicuries
Mev	Million electron volts
MHz	Mega hertz
μ g	Microgram
μ r	Microroentgen
ml	Milliliter (cc)
mm	Millimeter
mr	Milliroentgen
mrad	Millirad
Mrem	Millirem
N	Ions/cc
\bar{p}	Pressure in microns
ppm	Parts per million
PVC	Polyvinyl chloride
q	Unit charge/electron (1.6x10 ⁻¹⁹ coulomb)

r	Radius
rh	Relative humidity
sec	Second
μ	Micron
v	Velocity
V	volts

INTRODUCTION

Koller (1932) in a review of the early history of work with air ions has traced these studies back to 1785 when Coulomb experimented with the loss of charge of a metal conductor in air and found that a charged body would lose that charge in a repeatable manner.

After the discovery of X-rays by Roentgen in 1895, many further experiments were performed by J. J. Thomson, Ernest Rutherford, and J. S. Townsend who investigated the conductivity of gases produced by these rays. Numerous facts were discovered in these early experiments including the information that conductivity was produced by electrical charges of both signs. Although it was believed that the velocities of the positive and negative carriers were different, Zeleny (1900) was one of the first to establish this fact in 1899.

Ebert (1901) related soil respiration to the ionic content and free space charge of the lower atmosphere in the early 1900's. Further progress in the understanding of air ions was made by workers such as Hess (1928), who described the formation of air ions and their effect on the electrical conductivity of the atmosphere in terms of the known sources of radiation in the late 1920's.

The low concentrations of air ions caused many to doubt the importance of air ions as an environmental factor. Loeb (1934) stated, "The effect of the variation of ionic content in normal air as a health factor seems ridiculous in the extreme."

In the 1930's, a number of researchers studied the effects of air ions on animals and humans. An awareness of air ionization was given to many

others by Hansell (1945) following World War II when he outlined the efforts of German scientists working with air ions. In the 1950's, a number of experiments were conducted to obtain a better understanding of the effects of air ions on both humans and animals. These experiments were continued in more detail in the 1960's. Of the many experiments conducted, only a few have been with insects.

Present concern for the use of pesticides as the primary method for insect control has led to a renewed interest in studies of the effect of all environmental factors on insects in a search for other possible methods of insect control. Economic losses caused by insects are many millions of dollars annually. Damage from the European corn borer alone in 1968 has been estimated at \$161,287,000 (U.S. Dept. of Agric., ARS, Plant Pest Control Div. 1969).

Wellington (1946) has shown evidence that insect behavior is influenced by weather. Norinder and Siksna (1949) have, in turn, shown that air ions are one of the environmental factors that changes with weather.

The establishment of the effects of air ions on biological systems, such as insects, however, still remains to be firmly established and accepted.

REVIEW OF LITERATURE

Air in our natural environment is normally ionized by two main sources of energy. These are the radiation from outer space and the radiation emanating from materials in the earth's crust. The formation and characteristics of air ions, as well as their reported effects, have been included in the following literature review.

Formation of Air Ions

The rate of formation of air ions has been reported by both Hansell (1961) and Swan (1961) as approximately ten ions pairs per cubic centimeter per second at sea level where the air contains about 2.7×10^{19} molecules per cubic centimeter. Thus, at normal ionization levels of approximately 500-1000 ions per cubic centimeter, less than one ion is present in 10^{16} molecules.

Since the maximum ion density obtainable by artificial means according to Krueger (1968c) is about 10^6 ions per cubic centimeter, the maximum ratio of small ions to non-ionized molecules is approximately one in 27 trillion. Under natural conditions or most test conditions where much lower levels of ionization exist, this ratio is multiplied by several orders of magnitude.

Basic information on the formation of ions in the lower atmosphere is presented by Ivanov-Kholodnyi (1965). Tammet (1968) has also reviewed the causes of the formation of air ions. Their normal production is from natural sources of radiation including cosmic rays, radioactive materials in the soil, and radon and thoron in the atmosphere. Air ions are also

produced from high velocity winds or the breakup of water into fine particles such as in waterfall mist or ocean spray. It has also been found that ions may be produced by artificial methods such as thermionic generation (heated sources), radioactive materials or X-rays, ultraviolet photo-ionization, high-voltage or corona discharge, and high frequency fields. Unipolar ionized air that contains air ions of only one polarity is found only under laboratory conditions.

When sufficient energy is given to the orbital electrons of molecules by radiation, particles from radioactive materials or by other sources of energy, free electrons and positive molecular ions are produced. The free electrons remain for only a brief interval in the order of microseconds before they recombine or become attached to molecules of gases in the air or to condensation nuclei to form negative ions.

Jesse and Sadauskis (1955) have determined the average energy required for formation of an ion pair by alpha and beta particles as approximately 34 ev for the production of ions in air. The air ions in our normal environment are produced by energy from natural radiation at the earth's surface that is of both terrestrial and extra-terrestrial origin.

In the normal atmosphere, oxygen, water vapor, nitrogen, and carbon dioxide are the most important gases in relation to air ion formation. Since both oxygen and nitrogen are diatomic, ionization effects must be considered on a molecular rather than atomic basis. Negative ions of nitrogen are not formed, according to Loeb (1960). Therefore, the gaseous ions in air consist primarily of negative molecular ions of oxygen, and positive molecular ions of nitrogen and oxygen with the former

predominating.

Terrestrial radiation

Terrestrial radiation background comes from naturally occurring radioactive materials and fallout. Approximately 70 radioactive materials are found in nature, mainly among the heavy elements. Of these, there are three families of radioactive isotopes that account for the majority of background radiation. These are the uranium series (from ^{238}U), the thorium series (from ^{232}Th) and the actinium series (from ^{235}U). There are also a number of singly occurring radionuclides including ^{14}C , ^{40}K , ^{87}Rb , ^{138}La , and ^{147}Sm . Dudley (1959) lists ^{40}K as the most important among these.

The variations in the concentration of uranium in different types of rocks has been given by Lowder and Solon (1956). These concentrations ranged from 0.03 $\mu\text{g/gm}$ in ultrabasic igneous rocks to 120 $\mu\text{g/gm}$ in phosphate rock (Fla.). The concentrations of radioactive elements in the ground are generally highest in igneous rock (granite) and lowest in sedimentary rock (limestone). Faul (1954) reported that the thorium content of rocks varies from about 1 ppm for limestone to 8.1-33 ppm for igneous rocks with a mean value of 12 ppm.

Neither uranium nor thorium contributes greatly to the radiation background because of their specific activity and type of radiation except through their daughter products. The most important of these, radon (^{222}Rn) and thoron (^{220}Rn), diffuse into the atmosphere and contribute to the background level. Lockhart (1958) reported typical concentrations of these materials for various locations. Radon content varied from

17.2×10^{-4} curies/liter at Washington, D.C., to 0.1×10^{-14} curies/liter at Little America, Antarctica. Thoron content was 0.23×10^{-14} curies/liter and <0.001 curies/liter, respectively, at the same locations. The United Nations Report (1958) covering a number of areas including Japan, Great Britain, Austria, Sweden, and the Soviet Union indicates that the average concentration of radon in outdoor air may be taken as $(10 \text{ to } 30) \times 10^{-14}$ curies/liter. The distribution of many other radioactive materials has been tabulated by Eisenbud (1963).

Data on total background radiation levels are available from sources such as Solon et al. (1960). These data show a typical radiation level range of 11.7 to 12.5 $\mu\text{r/hr}$ for Philadelphia, Pa., to 19.2-22.9 $\mu\text{r/hr}$ for Denver, Colo. The mean annual dose for these cities is 99 and 172 mrad and a cosmic radiation level of 3.8 and 7.9 $\mu\text{r/hr}$, respectively. Large atypical radiation levels were found within a given city ranging from 17 to 53 percent greater than the highest normal levels. Calculations for the conversion of these background radiation levels to air ionization levels are shown in Appendix A.

Extra-terrestrial radiation

Ionizing radiations from the sun continually bombard the surface of the earth. The ultraviolet portion of the sun's radiation produces intense ionization in the outer atmosphere but contributes only a minor amount of energy at sea level. Ivanov-Kholodnyi (1965) indicates that cosmic rays cause greater ionization than solar radiation below 65-75 km.

At the earth's surface, cosmic rays consist of a mixture of energetic particles and X-rays. In addition to their direct ionizing action, cosmic

rays also produce radioactive materials in the earth's crust and atmosphere. The most notable of these are carbon 14 (^{14}C) and tritium (^3H).

The primary cosmic radiation consists of 85 percent protons and 14 percent alpha particles. Interactions of primary particles with atmospheric nuclei produce electrons, gamma rays, neutrons and mesons. At sea level, mesons account for about 80 percent of the cosmic radiation and electrons about 20 percent.

Cosmic ray intensity varies with latitude being about 15 percent higher above 60° latitude as compared with the equator. Lowder and Solon (1956) give data estimating the sea level dose at 40° N as 34 mrad/year. When the neutron dose produced by cosmic rays is added, the total dose is approximately 50 mrem/year. Data from the above sources show a rate of ion production from cosmic rays of from 1.5 to 2.8 ion pairs/cc/sec.

Air Ion Levels

Norinder and Siksna (1949) found levels of 800 to 2000 ions/cc with the positive ions predominating most of the time. Variations in ionization levels were found in relation to wind, humidity, and precipitation as well as the time of day. Martin (1952) gave values for typical atmospheric conditions of from 500-2000 ions/cc.

Kornblueh (1960) summarized average levels of small ions for a number of locations throughout the world. These data may only be regarded as approximate because of variations in the measuring and reporting techniques. They do, however, serve as a useful general reference.

Beckett (1961) determined that typical levels of air ions were approximately 500-1000 small ions of each polarity per cubic centimeter.

Hansell (1961) has given values for the ionization levels of the atmosphere near the surface of the earth as several hundred positive and several hundred negative ions/cc. He also noted that the number of positive ions is greater than the number of negative ions so that the air is normally positive with respect to the earth. Davis and Speicher (1961) in measurements of the outdoor air in the City of Philadelphia for a period of one year found an average hourly ion level mean of approximately 440 ions/cc. They also determined that the average mean negative ion levels increased by 36 percent to 600 ions/cc during periods of measurable precipitation. In addition, they noted a diurnal variation in ion levels as well as a correlation of ion levels with wind direction. Corrado et al. (1961) found the average ion levels to be 700 negative ions and 720 positive ions/cc in Richland, Washington.

References to other sources of data for air ion levels are given in Appendix D.

Characteristics of Air Ions

A description of the basic physics of air ions has been outlined by a number of writers, including Anderson (1963), Kranz and Rich (1961), and Swan (1961). The behavior of positive and negative ions after formation depends on a number of factors including the ion characteristics, the electric field, and the presence of condensation centers such as moisture or particulate matter.

Ion attachment coefficient

The probability of electron attachment per collision with a neutral molecule (or atom) is defined as the electron attachment coefficient, h . Values of h are strongly dependent on electron energy and vary widely with gas type. Morris and Schmeising (1958) have made extrapolations of ionization potentials of oxygen by the Lagrange formula to obtain a value of 1.044 eV for the first electron affinity of oxygen. Bradbury (1933) has reviewed the theory of the formation of negative air ions from oxygen and oxygen mixtures and determined values for the probability of the attachment of an electron to an oxygen molecule. Price (1958) has indicated that h for oxygen and water vapor is approximately 10^{-4} .

Recombination

When positive and negative ions (or electrons) exist together, recombination occurs forming neutral molecules. Recombination losses have been listed by Loeb (1939). These are initial recombination, preferential recombination, columnar recombination, and volume recombination.

For all of the above processes, the rate of recombination may be expressed by

$$\frac{dN(+)}{dt} = \frac{dN(-)}{dt} = \alpha N(+)N(-)$$

where α is the recombination coefficient and $N(+)$ and $N(-)$ are the densities of the positive and negative ions, respectively. Due to the difficulty of obtaining meaningful values for α , direct calculation of these losses is not possible in practical situations. Price (1958) has given values for α of 10^{-6} to 2×10^{-6} cm³/sec when the negative charge

exists as negative ions and 10^{-7} to 10^{-10} cm^3/sec for electrons.

Siksna (1964) has given information on the calculation of recombination coefficients of small ions by using a correction term in the exponential function for the enhancement of the capturing cross section due to the electrical forces acting between oppositely charged ions. Siksna (1965) has discussed a number of the formulas for determining the coefficients of recombination of ions including those proposed by Thomson, Gunn, Natanson, and Bricard. Whitby and McFarland (1961) obtained approximate solutions for the decay rate of ions due to recombination in a space containing aerosols and showed that precipitation of the aerosol occurred at a rate dependent on the total charge density of the small ions and particles and the mobility of the charged particles.

Mobility

One of the important characteristics of air ions is their mobility or mean velocity in an electric field. The most common units of measurement are in centimeters per second per volt per centimeter. This is often abbreviated as $\text{cm}^2/\text{volt-sec}$. Tammet (1968) and Siksna and Lindsay (1959b) have presented excellent discussions of the ion mobility spectra and the complications in determining such data.

Studies of ion mobilities show that air ions have a mass larger than a single molecule and age or become larger with time. Schaefer and Dougherty (1961) indicate that both positive and negative ions attach themselves to other molecules, particularly molecules of water.

Mobility is dependent on the ion mass, its charge (usually that of a single electron), and the mean free path of the ion in the normal

atmosphere. The mean free path of an ion is less than that of an uncharged particle of the same mass because of the attractive forces exerted by the electrostatic charge.

Ions have been arbitrarily classified on the basis of their mobilities into small, intermediate, and large sizes. Anderson (1963) has defined small ions as those having mobilities from 0.1 to $20 \text{ cm}^2/\text{volt-sec}$, intermediate ions as those having mobilities from 0.01 to $0.1 \text{ cm}^2/\text{volt-sec}$, and large ions as those having mobilities of less than $0.01 \text{ cm}^2/\text{volt-sec}$. Duffee and Schutz (1961) have termed small ions as those having mobilities from $1.0\text{--}2.0 \text{ cm}^2/\text{volt-sec}$, intermediate ions as those having mobilities from 0.01 to $1.0 \text{ cm}^2/\text{volt-sec}$, and large ions as those having mobilities less than $0.01 \text{ cm}^2/\text{volt-sec}$. Tammet (1968) has specified intermediate ions as those having mobilities of 0.06 to $2 \text{ cm}^2/\text{volt-sec}$ and large ions as those having mobilities of 0.001 to $0.06 \text{ cm}^2/\text{volt-sec}$. These differences in values within the field of air ionization research show the need for uniform methods of expressing results.

Jonassen and Wilkening (1965) have given values for the average mobility of small positive ions of $0.016 \text{ cm}^2/\text{volt-sec}$ and of small negative ions of $0.02 \text{ cm}^2/\text{volt-sec}$. They also have shown that the small ion concentration for mobilities greater than $0.01 \text{ cm}^2/\text{volt-sec}$ may be correlated with polar conductivity measurements.

A study of the absolute mobility of gaseous ions in pure gases has been reported by Bradbury (1932a) following the methods of Tyndall and Grindley (1926). Bradbury determined a mobility, k , for positive ions of

1.60 $\text{cm}^2/\text{volt-sec}$ and for negative ions of 2.21 $\text{cm}^2/\text{volt-sec}$ at an age of 0.07 second. The values determined by Bradbury are probably more accurate than the earlier values of 1.36 $\text{cm}^2/\text{volt-sec}$ and 1.87 $\text{cm}^2/\text{volt-sec}$ obtained by Zeleny (1900) or 2.16 $\text{cm}^2/\text{volt-sec}$ obtained by Loeb (1923), and 2.18 $\text{cm}^2/\text{volt-sec}$ obtained by Tyndall and Grindley (1926) due to a greater emphasis on the purity of the air. Humidity is also a definite factor in ion mobility. Hansell (1961) has noted that negative air ions have mobilities about 1.5 times greater than positive ions at low humidities. As the humidity is increased, the mobilities of both positive and negative ions decrease and the two mobilities approach equality.

Ion size

Anderson (1963) has presented data indicating that the particle radius of intermediate ions varies from approximately 10^{-6} cm for ion mobilities of .01 $\text{cm}^2/\text{volt-sec}$ to a radius of 0.5×10^{-6} cm for ion mobilities of 0.1 $\text{cm}^2/\text{volt-sec}$. For intermediate ions with mobilities of 0.001 to 0.12 $\text{cm}^2/\text{volt-sec}$, Nagy (1961) has given the size as 0.003 to 0.03 μ . Rich et al. (1959) have shown by experimental evidence that the concept of equivalent radius provides a good estimate of the average size of submicron particles in polydisperse aerosols.

Anderson (1963) has indicated that size differences between ions may be expressed in terms of relative mobilities. He gave values for the mobility of negative ions as about 40 percent greater than positive ions.

Air ion-condensation nuclei reactions

A number of basic studies have been made to obtain information on the interactions of air ions and condensation nuclei. Keefe et al. (1959) have arrived at combination coefficient ratios by a consideration of the distortion of ion trajectories and on the basis that a charge equilibrium should exist in aerosols in accordance with the Boltzmann law. Ruhnke (1961) used these ratios to find a relationship between the small ion density and the density and radius of condensation nuclei. From this, the radius of particulate contamination was made by the measurement of ion densities.

Schaefer and Dougherty (1961) have shown that the loss of small ions is dependent upon the number of aerosol particles and that the ratio of ion loss per aerosol particle was very close to one. Kranz and Rich (1961), however, found a smaller loss of air ions with higher numbers of condensation nuclei. The values given by Kranz and Rich (1961) for the number of condensation nuclei for clean or "white" rooms was 200-300/cc as compared with 20,000-50,000/cc for the average laboratory.

Air Ion Generation

One of the major problems in work with air ionization is the generation of the air ions. Martin (1952), Nagy (1961), and Tammet et al. (1968) have covered in detail the various sources of air ions. These include ion production by corona discharge, thermionic emission from materials at high temperatures, radioactive materials, radiation sources such as X-rays, ultraviolet photo-ionization, and separation of charges by

physical means. The latter method includes many phenomena that occur in nature such as the formation of ions from water droplets in a waterfall or ocean spray and separation of charges by rapidly moving dust particles.

Corona generators utilizing discharge from high voltage wires were used extensively by many of the early experimenters with air ions. Norinder and Siksna (1952c) have discussed ion generation by negative wire corona, and Siksma (1953b) has discussed the spectra of ions formed by positive corona discharge.

Tammet (1959) has described a typical corona generator which gave concentrations of 10^6 ions per cubic centimeter at a distance of 0.5 meter. While Tammet has indicated that the generation of nitrogen oxides and ozone was negligible in this unit, these factors have been a major problem with all corona generators as detailed by Skilling and Beckett (1953).

Thermionic generation was one of the early methods developed in this country. The construction of thermionic generators has been described by Hicks (1951, 1952a). Skilling and Beckett (1953) have described both thermionic generators and those using a radioactive polonium source in detail.

Hessemer (1954) has shown that smokes produce a pronounced effect on the emission of ions from hot filaments. He attributed this action to surface reaction between the smoke and the filament and to strong space charge forces originating from smoke ions.

Balloelectric or hydro-aeroerators which form ions by the evaporation of small drops of water have been used extensively in Russia to produce

ions. This principle has been described by Ternyavsky (1955).

The most widely used type of ion generator in recent experimental work has been that using radioactive material to ionize the air molecules. Discussion of the generation of air ions by this method may be found in papers by Norinder and Siksna (1951c) describing the generation of air ions by a polonium generator and Siksna and Lindsay (1959a) giving details of ion generation by a tritium source. The actual ion production for a given strength of radioactive source was found to be greatly dependent on the physical construction of the ion generator and relatively independent of the separating potential used beyond a "threshold" level for a given air flow. The air flow rate, however, was found to be an important parameter in the ion output.

For the tritium generators reported, the output was almost directly related to the air flow rate at low flow rates. Martin (1954a) has discussed the production of unipolar air with radium isotopes. The factors in the selection of possible radioactive sources were evaluated and a polonium foil selected as the most desirable source for ion production.

Siksna and Lindsay (1959a) and Tammet (1968) have discussed the calculation of the number of ions that are produced by a radioactive source from knowledge of the activity of the source, the average energy available per disintegration, and the required energy per ion pair produced.

The ion output from radioactive sources can be determined experimentally. The measured output will always be less than the theoretical

output. A number of reasons that are responsible for the lowered output have been listed by Martin (1954b). These include losses due to ion recombination, absorption of radiation in backing materials and structural members, and losses of ions due to the separation process.

The production of air ions in air at atmospheric pressure by ultra-violet light from a quartz-mercury arc has been described by Norinder and Siksna (1952b). Tammet et al. (1968) have listed as a major defect of photoelectric air ionizers, the production of biologically active gases.

One unconventional method for generating low-energy negative ions is that described by Muschlitz et al. (1961). Ions with a narrow energy spread are produced by the intersection of a jet of gas with an electron beam. O^- ions and O_2^- ions were produced with a total energy spread of 4 ev.

Air Ion Measurement

Measurement of ion densities and characteristics is one of the important aspects of research with air ions. Beckett (1961), Frey (1965), and Krueger et al. (1962) have emphasized the importance of measurement and specification of the ion levels and size distribution in the reporting of experiments using air ions.

The fundamentals of air ion measuring techniques are found in books on atmospheric electricity such as those by Fleming (1949) and Chalmers (1957). The basic components of all measurement systems consist of devices for sampling the air, collecting the ions, and giving a readable indication of ion density. A general discussion of ions in the atmosphere

and their measurement parameters such as recombination coefficients, mean life, and mobilities has been given by Wait and Parkinson (1951).

Ion collector devices have been described in a number of papers. The aspiration condenser introduced by Zeleny (1900) has been used as one of the basic methods of measurement for over 70 years. Ebert (1901) adapted it to the measurement of air ion density, and it is often referred to as the Ebert counter. Norinder and Siksna (1949) have described the Ebert counter in detail, and Anderson (1963) and Fleming (1949) have described a similar device that is referred to as the Gerian conductivity chamber. Beckett (1961) has suggested that a practical design limit for these or other collectors is an air volume flow rate sufficient to provide an ion current of 10^5 ions/sec for a sensitivity of 20 ions/cc. Tammet (1968) has given a description of many of the methods which have been used for air ion measurement.

Improvements to the coaxial-type ion collector have been described by Knoll (1959). The stray electric fields near the cylinder edges were reduced, the airstream velocity was lowered, and the polarizing voltage was reduced to increase the accuracy and reliability.

Another of the basic methods of ion density measurement is the Beckett probe as described by Krueger et al. (1958). A disk target surrounded by a grounded shield is used to measure the ions impinging on its surface. No polarizing potential is necessary, but the sample area must be large enough to obtain a suitable current indication without disturbing the airflow or shielding the specimen area.

Parallel plate devices are also commonly used and Beckett (1961) has

indicated that their use is preferable where mobility distribution is a major consideration of measurement. A typical parallel plate unit is the Wesix ion collector described by Winsor and Beckett (1958).

When speed of response is not required, extremely sensitive measurements with good stability may be made by the "rate of drift" method as outlined by Price (1958). The electrometer input resistor is eliminated and the rate of change in voltage is observed as the current flows into the input capacity of the electrometer. This allows measurements of currents as low as 10^{-16} amperes with a vibrating reed electrometer. One of the newest methods used for the separation and measurement of gaseous ion states is that of beam foil spectroscopy. Fink (1968) has separated N^+ and N^{2+} ions in the range of 4000-4500 angstroms.

The effect of space charge on the measurement of air ions at high concentrations has been noted by Siksna and Metnieks (1953). Further consideration of this effect on measurement accuracy has been given by Siksna and Lindsay (1959b). They point out that in mobility determinations where current voltage characteristics are obtained, the effects of space charge cannot be neglected at low voltages and high ion concentrations. Their data show that for typical dimensions of a Weger condenser with an inner radius of 1.5 mm, an outer radius of 10 mm, and with concentrations of ions in the order of 10^6 ions/cc, the effects of the space charge must be considered unless the applied potential is in the tens of volts. A large volume of literature exists covering techniques and measured values for ion levels and mobilities. Some of

this literature is listed in Appendix D.

Effects of Ions

Insects

The available literature on the effects of air ions on insects is of a very limited nature. The earliest reported work with insects was conducted by Chase and Wiley (1935) who experimented with flies, Drosophila melanogaster. In cultures exposed to ionized air from both a polonium source and a corona discharge, a definite effect was observed, consisting of coloration and subsequent death of larvae. The levels of ionization and the polarities of ions that were used were not reported.

Edwards (1960b) found that the flight activity of the blowfly, Calliphora vicina, was increased in the presence of positive ions of $3,560 \text{ ions/mm}^2/\text{sec}$ over a background level of $127 \text{ ions/mm}^2/\text{sec}$. Maximum activity occurred approximately three-quarters of an hour after first exposure to the ions. He also found that activity returned to normal levels with continuing exposure, which indicated a form of adaptation. No significant effect was found with negative ions. It should be noted that he stated that he knew of no published record as of that date, regarding the effects of air ions on insects.

Levengood and Shinkle (1960) found that Drosophila melanogaster yielded more progeny than the control groups when the barometric pressure rose during the mating period and less with decreasing pressures. This might be taken as indirect evidence of a possible influence of air ions on insects since the change in air ion concentration has been correlated

with the variations in radioactive emanations from the soil by Norinder and Siksna (1950), and this in turn would be a function of changes in barometric pressure.

Levengood and Shinkle (1961) in a later study found that when cultures were subjected to an electric field, average progeny yield increased by over 34 percent and the variations in yield attributable to pressure were dampened. They felt that there was an interaction of the decreasing pressure (increasing air ion level) and the electrical field which in effect shielded the insects. Other reactions of insects to electric fields have been reported by Schua (1952) in which he found increased foraging and food uptake during periods of electrical disturbances and by Steiner et al. (1961) in which unusually high trap catches of insects were observed in advance of storms.

Edwards (1960a) experimented with the influence of electrical fields on the adult diptera, Drosophila melanogaster and Calliphora vicina. He found that activity in Drosophila was reduced by sudden exposures to potential gradients as low as 10 volts/cm.

Edwards (1961) also studied the influence of electrical fields on the pupation and oviposition in the phantom hemlock looper, Nepytia phantasmaria. Data obtained in these experiments showed that the development of Nepytia pupae and also the number and location of eggs deposited by the adults was influenced by the field of 180 volts/cm. The 50 percent emergence time was delayed by approximately one day for pupae subjected to the continuous electric field, and the difference was statistically significant as compared with the controls.

Wellington (1946) has noted the confused pattern of research results which have been obtained by a number of investigators who have tried to determine the effects of pressure variations on insect activity. Changes in both insect activity and catches of insects have been correlated with periods of low pressure, a time at which positive ion levels have been shown to increase. The results reported by Wellington may have been caused by changes in the air ionization levels rather than the fields per se, since it is difficult to separate the effects of fields and pressure changes from the effect of the change in air ionization levels that they would produce.

Bluh (1962) studied the flight endurance of flies, Lucilia sericata and Muscina stabulans. An excess of negative ions produced increased insect activity. Haine (1957) found variation in the activity and molting rates of aphids, Myzus persicae, at certain times even under constant temperature and light conditions. Haine (1962), in further experiments on aphids, demonstrated that negatively ionized air produced increased molting and a rise in negative ion density produced increased activity. Haine et al. (1964) found that increased molting of aphids was produced by either a drastic reduction of positive ion levels or a sudden increase in negative ion levels.

Krueger et al. (1966) in studies of air ion effects on the silkworm, Bombyx mori, found an increase in larval growth, increased biosynthesis of catalase peroxidase and cytochrome C oxidase, earlier onset of spinning, an increase in the weight of cocoons, and development of heavier silk layers (not statistically significant).

Maw (1965) found that the flight of the blowfly, Phaenicia sericata, was definitely influenced by air ions. Insects exposed to ion currents of about 3.4×10^{-11} amperes, had longer and faster flights than those in laboratory air. Negative ions also gave faster and even longer flights than positive ions with some flight lengths approaching three times the length of untreated controls. His results, however, were based on selected data grouped around the mean because of the variability he encountered in flight time. Only selected insects of those that flew were used, which may have influenced the results.

Details of Maw's experimental procedure were extremely poor and gave no indication of the strength of the ion source, the potential used in measurement, or the dimensions of the test apparatus. The reported current of 3.4×10^{-11} amps would indicate an ion flux of about 21×10^7 ions/sec assuming singly charged ions.

Ross (1965) has stated that the metabolic rate of insects increases with activity by a large factor over that of the insect in an inactive state. The CO_2 output may therefore serve as a useful indication of metabolic rate or activity and has been measured with infrared gas analyzers by Hamilton (1959) and Turner (1969). Other methods for CO_2 measurement include the use of a diaferometer by Punt (1956) and gas chromatography by Carlson (1966, 1968). Similar measures of metabolism have been made by Chaudhry and Kapoor (1967) using the Warburg apparatus and Fourche (1967) using an electronic respirometer.

The latest paper found on the subject of air ions and insects is that of Helson and Penman (1970). In investigations of the flight

activity of Porina moths, Wiseana spp., increased flight activity was noted 15 to 30 hours before the approach of a low pressure cold front. A degree of correlation was obtained between the increase in flight activity and the increased ion concentrations related to the approach of a cold front. Laboratory experiments using both positive and negative ions suggested that emergence might be related to the positive to negative ion ratios.

Microorganisms

Studies of the effects of air ions on simple forms of life have been conducted by a number of investigators. Professor A. L. Tchijevsky (1933) reported a number of experiments showing growth inhibition of organisms such as Micrococcus pyogenes. Krueger et al. (1957b) observed increases in death rate from unipolar ionized atmospheres for Micrococcus pyogenes var. aureus.

Worden and Thompson (1956) found statistically significant differences in rate of proliferation for pure strain L cells (Earle's). Reproduction was accelerated under conditions of negative ionization and decelerated under conditions of positive ionization. Krueger et al. (1957a) determined that unipolar air ions had lethal effects on microorganisms, and Pratt and Barnard (1960) found inhibitory effects on Penicillium notatum.

Krueger (1961) reported a number of experiments in which a small, but lethal, effect was observed for bacteria. Krueger (1968b) in reviewing a number of experiments on the effect of air ions on microorganisms

concluded that unipolar ionized atmospheres of either polarity had a moderate inhibitory effect on growth of bacteria or fungi and a lethal effect on vegetative cells exposed in small droplets (5λ-50λ).

Sharp (1967) found that exposure of the fungus Piccinia striiformis to natural ion levels resulted in reduced germination as the concentration of intermediate negative ions (mobility exceeding $0.03 \text{ cm}^2/\text{volt-sec}$) increased.

Plants

Krueger (1968a), in reviewing the early observations of the relationship of atmospheric electricity and plant growth, has noted that as early as 1748 l'Abbe Nollet found responses in germination and growth of plants that were placed under charged electrodes. Following this, in 1775, Father Giambattista Beccaria and in 1783, Bertholon were among the earliest to study the causal relationship of atmospheric electricity and plant growth. During the 19th century, Sturgeon (1846), Grandeau (1878), and others concluded that atmospheric electricity was important in the plant growth cycle. Blackman (1924) studied the growth of coleoptiles of barley seedlings and observed increases in growth rate from discharge currents of 0.5×10^{-14} amperes from a point source 20 cm above the seedlings. Air ions were assumed to act only as the current carrier and not as active agent.

Smith and Fuller (1961) reported that positive CO_2 ions stimulated growth in algae and that effects in plants were through release of the growth hormone, indole-3-acetic acid (IAA).

Krueger et al. (1962), in studies of the influence of positive and

negative ions on the growth of oat seedlings, Avena sativa, found that either positive or negative ions produced significant stimulation of growth as measured by stem length, integral elongation, and dry weight. The extent of growth increase was related to the ion density, and the minimum current observed as producing a measurable difference in growth was 4.3 to 4.6×10^{-13} amperes per plant. Krueger et al. (1963b) and Krueger et al. (1963c) in further investigations of the mechanism of air-ion-induced growth found an acceleration of cytochrome C production for either positive or negative ions. Krueger et al. (1964a) and Kotaka et al. (1965) in studies of barley seedlings, Hordeum vulgare, grown in iron-free nutrient solutions, found that air ions of either charge accelerated the onset of chlorosis.

Krueger et al. (1964b) attempted to determine if atmospheric ions functioned only as a link to supply current. O_2^- and O_2^+ ions in concentrations of 1.8×10^4 /cc accelerated growth rate, CO_2^- and CO_2^+ ions inhibited growth, and O_2 or CO_2 without ionization produced no effect. Krueger et al. (1965) showed that growth of barley seedlings in atmospheres with abnormally low concentrations of air ions, (ca. 30(+) and 30(-) ions/cc), produced significant reductions in growth as measured by integral elongation, fresh weight, and dry weight. Plants also had soft leaves and lacked normal rigidity after 30 days.

Biological and physiological effects

The literature on biological and physiological effects of air ions is very extensive. Kornbluh (1958) has given a review of some of the early literature. A small and select number of references are cited to

illustrate the variety of effects that have been observed.

Dessauer (1931) in a comprehensive series of experiments on human patients found that in most cases positive ions produced feelings of fatigue, dizziness, headaches, roaring in the ears, and nausea. Although exceptions were noted, negative ions produced none of these effects and generally gave a feeling of exhilaration. Blood pressure readings of healthy individuals were increased slightly by positive ions but lowered 5 to 10 mm by negative ions. The rate of respiration was increased by positive ions, but patients breathed more quietly with negative ions. He also noted an apparent increase of oxygen consumption under the influence of positive ions. Dessauer also found therapeutic effects of ionized air in ailments such as high blood pressure, rheumatism, gout, neuritis and neuralgia, bronchitis, asthma, and heart and arterial diseases.

When hamsters were subjected to negatively ionized air, Worden (1953) found the weights of individual organs in relation to total body weight significantly larger for the heart, adrenal, kidney, testis, seminal vesicle, and epididymis. The spleen and liver, however, were unaltered as compared with the control animals. Worden (1954a) in studies of the pH of the blood of hamsters found that animals exposed to negative ionization showed an increased pH with exposure to negative ionization but only an insignificant decrease with positive ions.

At the cellular level, Worden (1961a) found that negative ionization increased the rate of proliferation of cells such as Earle's strain of L. mouse fibroblasts MCTC, clone 929, and that positive ionization decreased their multiplication rate.

Worden (1961b) cites experiments in which the growth of explants of chickens cultured in negatively ionized air averaged one and one-half times the size of their controls while those grown under positively ionized air were nine-tenths the size of their controls.

Yaglou et al. (1933) in a comprehensive series of experiments on humans in a psychrometric chamber found that with small ions having average mobilities of $1.3 \text{ cm}^2/\text{volt-sec}$ and with ion densities of 5,000–1,500,000 ions/cc, changes were produced in the subjects' metabolism, respiration, pulse rate, and blood pressure. Effects with positive and negative ions were similar, regardless of the concentration. The major effect noted was a normalizing influence of both positive and negative ions in which physiologic processes were accelerated if below normal and decreased when above normal. Although the physiologic responses to the positive and negative ions were similar, positive ions produced unpleasant sensations such as headaches and irritation of the nose and throat while negative ionization produced desirable sensations and relaxation.

In work with transplanted rat carcinoma, Eddy and Sokoloff (1951) found that growth of the tumors was inhibited for rats kept under negative ionization as compared with controls. Eddy et al. (1951) also demonstrated a similar retardation of tumor development with applications of negatively ionized air at densities of 6,000–8,000 ions/cc. At the end of four weeks, the size of tumors in treated animals was approximately half that of the controls.

In an often quoted experiment, Krueger and Smith (1957, 1958a, 1958b)

were able to demonstrate that the ciliary rate of excised rabbit trachea was influenced by air ions. Positive ions decreased the normal rate from 1,400-1,500 beats per minute to 1,100 beats per minute. Negative ions, however, produced a rise in ciliary rate to 1,600 beats per minute and occasionally as high as 1,700 beats per minute. They were able to reverse and restore the lowered ciliary rate caused by positive ions to normal by the application of negative ions. They also determined that negative ions did not affect the ciliary rate in atmospheres of N_2 or CO_2 but did in O_2 .

Krueger and Smith (1960) have advanced the hypothesis that positive ion effects are mediated by the release of free 5-hydroxytryptamine, and negative ion effects depend on their ability to accelerate the enzymatic oxidation of 5-hydroxytryptamine. Krueger et al. (1963a) carried on further studies on the effect of positive CO_2 ions on the blood level of 5-hydroxytryptamine in mice.

Animals

Studies of the effects of air ions on animals have extended through several decades. Tchijevsky (1926) noted the influence of ionized air on the motor and sexual activity of animals. Herrington and Smith (1935) found no significant differences in mean weights or in hemoglobin of albino rats exposed to high concentrations of light negative ions (mobility approximately one $cm^2/volt\text{-}sec$) as compared to controls. The mean activity of the experimental group was, however, significantly greater than controls for ages greater than 175 days.

Hillstrom (1961) applied negatively ionized air to the environment of poultry houses. He found that the average weight per bird was 3.6

pounds in the group subjected to air ions during their growth period as compared with 3.32 pounds for the control group under artificial light. Application of ionized air was started when the birds were two weeks old. Mortality was 51 birds in the test group and 90 birds in the control group. A second test in which negatively ionized air was applied the first day the chicks were put under the brooders gave an average weight per bird of 3.34 pounds for the test group and a mortality of 61 as compared with 3.26 pounds and a mortality of 91 for the control group. The feeling that too early an exposure might have been a retarding factor was expressed in the report.

Kuster and Frieber (1941, 1942, and 1943) have reviewed the literature on the influence of ionized air on higher animals. Their experiments with mice and rats with both spontaneous and transplanted tumors showed that life could be substantially prolonged by applications of negatively ionized air in contrast with control animals that had not been so treated. Investigations with tuberculous animals also indicated a favorable influence of ionized air.

Haikamara (1952) in studies of tumor development for implanted tumors in mice found that, at average levels of negative ionization of 9,000 ions/cc, less than 20 percent of the mice developed tumors, none metastases; at average levels of positive ionization of 12,500 ions/cc, 35 percent of the mice developed tumors, all of which metastasized; and in the controls at ion densities of 90 negative ions and 62 positive ions/cc, 50 percent of the mice developed tumors, three-fourths of which metastasized. In weight gain studies conducted in conjunction with these tests, no consistent trend of weight gain was found in relation to the

positive, negative, or neutral levels of ionization used.

Holloway (1952) in studies of the physiological effects of ionized air on the growth of the pituitary-adrenal system of normal rats found a cyclic variation in weight gain of animals subjected to both positive and negative ionization in comparison with controls. For negative ionization, there was a progressive increase in weight of the test group as compared with controls. This was more pronounced in females than in males, up to the 35th day of the application of ionization when a pronounced drop in weight of the experimental animals occurred as compared with the controls. The test group lagged the control group until the 57th day when they began to catch up with the controls. At the termination of the test on the 77th day, they had regained the weight advantage shown on the 35th day.

The weight reversal in Holloway's studies may offer an explanation for some of the conflicting reports on the influence of ionization on weight gains since conclusions may have been drawn on the basis of different periods in the cycle of relative weight gains. Similar cyclic changes were also noted in adrenal weight, cholesterol and ascorbic acid between the treated animals and the controls.

Rinfret and Wexler (1953, 1954) in studies of adrenal responses of rats subjected to a predominance of positive ions found that the pituitary-adrenal system of male rats was activated and that the stimulus appeared to be of a stressful nature. Nielsen and Harper (1954) found that for rats maintained in an atmosphere of predominately positive ionized air, for periods of four hours, the succinoxidase activity of the adrenal gland

declined significantly, an effect opposite to that of the stimulus of electric shock. Negatively ionized air produced a slight but not significant rise.

Krueger et al. (1963b) have found that high concentrations of positive ions slow mucus escalator, induced vasoconstriction, contracted the posterior wall, and induced vulnerability to trauma in the tracheal mucosa of animals. They also demonstrated that CO₂ must be present to cause these effects and that the physiological effects on the trachea could be duplicated by the intravenous injection of 5-hydroxytryptamine.

Brown and Stone (1965) in studies of the effects of negative air ionization on the growth rate of pigs found a large degree of variability in their experiments between controls and test groups. On the basis of their data, they concluded there was no advantage in providing negative air ions in the environment of weanling healthy pigs.

From the details provided, it is apparent that there were several possible causes for the test variability. First, the pens rested on plywood floors and there was no return path for the ion current. Second, plastic hovers were used that could become highly charged. Third, the relative humidity was not controlled and the particulate matter concentration was not monitored, thus leading to an uncertainty as to the equivalence of the condensation nuclei concentrations between the test groups and controls. All of these factors could contribute to variability in the actual ion intake of the pigs and influence the results. There was also considerable variability between the replications for the controls in terms of their average daily gain and pounds of gain per pound of feed.

For example, in the second test where ionization was applied for eight out of twenty-four hours, the average daily gain of the two controls was 0.689 and 0.967 as compared with gains for the treated animals of 0.929 and 0.822, respectively. This degree of variability in the control groups makes it difficult to arrive at any valid conclusion as to the effect of air ions.

Jacob et al. (1965) also found extreme variability in test results for the weight gain of pigs exposed to positive and negative ionization in a series of seven tests at ratios of artificial to natural ion densities of approximately 20 to 30. Three of the tests indicated no effects while one test showed positive ions produced less average daily gain, a second showed natural conditions produced less average daily gain than either polarity of ions, a third showed negative ions produced substantially less average daily gain, and a fourth showed negative ions produced greater average daily gain.

The authors concluded that even if no specific effects were proven, the observed differences in the data were of such a magnitude that the possibility that air ions could influence the growth rate of swine under certain conditions could not be dismissed.

Duffee and Koontz (1965) found that, in experiments designed to test whether stress is a necessary precondition for ionized air to affect behavior as hypothesized by Frey (1959), ionization of either polarity affected maze learning of rats irrespective of stress. The effect of negative ionization on the stress-maze learning of older rats was particularly outstanding. When animals that had spent 18 days in an atmosphere

with 2.9×10^5 positive ions/cc were transferred to an atmosphere containing 1.4×10^5 negative ions/cc, the water-maze performance improved 350 percent.

Bachman et al. (1966) found that the exposure of rats to concentrations of ions of either polarity produced pronounced effects on activity, attacks on the aluminum foil ground plate, urine output, defecation, sleeping period, and respiration rate. The lower concentrations of ions were generally most effective in producing changes.

Dobie et al. (1966) in one of the latest tests with poultry, found a large variability in weight gain for Japanese quail subjected to normal, positive, and negative ion environments. Negative ions produced the lowest body weight at three weeks.

Hansell (1961) stated that Russian experiments with animals placed in almost completely deionized air have indicated the probability that we cannot live without ions in the air. In studies of longevity of animals exposed to radiation reported by Henry (1961), several experimenters found increased life spans for animals exposed to radiation as compared with controls. Although these experiments were concerned with radiation level and not air ions, the difference in air ionization levels under the experimental conditions may offer some explanation for the results obtained.

Humans

Studies of the effects of air ions on humans have occupied a great deal of attention both in the United States and abroad. A large amount

of experimental data has been obtained, and several hundred references have been accumulated concerning air ionization research with humans. A limited number of references from the total literature that are representative or historically significant are reviewed here.

Thomson (1913) in some early observations of the CO₂ output of people and animals noted differences in CO₂ output during different days and concluded "that a number of persons should be similarly affected gave presumptive evidence that the cause lay not in the individuals but in the conditions of the atmosphere." Observations like these led many researchers such as Dessauer (1931) and others to investigate atmospheric electricity and air ions as a factor in human behavior.

Frey (1961), in summarizing many of the previous experiments of the effects of air ions on human behavior, listed effects on sensation, reaction time, activity, and emotion as areas in which behavioral effects have been shown..

Duffee and Schutz (1961) reviewed several of the experiments concerned with human behavior including a number of the postulated mechanisms for the effects of ions on humans. These include the electrical theories of Hicks and Beckett (1956), Dorno (1957), and Tchijevsky (1940); chemical theories by Krueger and Smith (1959) and Worden (1954b); and the hormonal theory by Frey (1959).

Frey and Granda (1961) reported their findings on the controls necessary for experimental work with humans and suggested that subject grounding, careful ion measurement techniques, and ion distribution control as well as avoidance of "shadow effects" are essential for

reliable results. They also suggested that some type of stress is a necessary precondition for ion effects to occur.

Human comfort has been related to the ion content of the atmosphere by Hutchinson (1944) and Murphy (1954). Both present arguments that the balance of ions normally found outdoors should be maintained in enclosed spaces.

Winsor and Beckett (1958) have reported that the average breathing capacity of subjects was reduced from 35 liters per minute, before ionization, to 25 liters per minute after a ten-minute exposure to positive ions.

Lazarev and Bulanova (1937) found that ionization affected the central nervous system sensitivity. Beckett (1954) has emphasized that the level of air ionization is an important environmental factor that should be maintained.

Yaglou (1935), in a study to find out whether negative ions in concentrations of about 10^6 /cc had an influence on physical efficiency as indicated by Schneider's cardiovascular rating, found that changes were variable and too small to draw any conclusions. Barron and Dreher (1964) were also unable to obtain conclusive results for their hypothesis that ionization would improve the effects of stress or fatigue in a series of psychomotor tests. Chiles et al. (1960) reported that breathing air with an excess of positive or negative ions had no discernible effect on human attitudes or ability to perform complex mental tasks.

Frey (1959) has offered the hypothesis that negative ions stimulate the secretion of the gluco-corticoids and positive ions either stimulate

the secretion of the mineralo-corticoids or inhibit the gluco-corticoid secretion. He cites the results from a number of previous research projects to support this hypothesis.

Weber (1948) explored the reaction time of young pupils in relation to the ionization of the F_2 layer. He found that his subjects fell into one of three groups. There were those whose rate of response increased with increased ionization of the F_2 layer, those whose response decreased, and those who oscillated between groups. The conclusions drawn by Weber, although interesting, are open to criticism since the F layers are at heights of several hundred kilometers above the earth's surface. This seems like an illogical correlation without providing correlation between the ionization level of the F_2 layer and the ion levels for the subjects.

The possible effect of air ions on reaction time has also been explored by Knoll (1958). Concentrations of approximately 2×10^9 ions/sec incident on the subject's face were found to produce inconsistent variations in reaction time. Further experiments by Knoll (1959) produced statistically significant results showing that small concentrations of inhaled air ions, either (+) or (-), reduced reaction time, but that large concentrations increased reaction time.

Rheinstein (1961) has discussed the difficulties of obtaining statistically significant data on the effect of air ions on reaction time because of the extraneous factors and the individual variability which are difficult to control for human subjects. He reported no significant effect of air ions on optical movement. Knoll et al. (1961) found statistically significant effects on reaction time but no predictable

direction of the effect for either positive or negative ions.

McGurk (1959) in studies of performance of work tasks by college-age males found no statistically significant difference in performance between environments of no ionization and positive and negative ionization levels of about 8,000 ions/cc. He did, however, find that with negative ionization the subjects were able to judge whether the air was ionized at a level such that the distribution of judgments differed from a chance distribution at the one percent level. He also found that, with positive ionization, the proportion of unpleasant reported feelings compared to the control conditions again differed at the one percent level from a chance distribution.

Medical therapy is also an area in which there is extensive published literature on the use of air ions. Only a few references are cited to illustrate the variety of applications in which air ions have been used. Wehner (1962), Levine et al. (1961), and Gualtierotti et al. (1968) have given extensive reviews of the applications and bibliographies for the use of air ions in medical therapy. Verdu (1955) has discussed the use of negative ions in the treatment of rheumatics. Tchijevsky (1939) has reported success in treating hypertension with negative ions. Pisani (1945) has noted the use of negative ions in treating whooping cough. Minehart et al. (1961) have found artificially ionized air helpful in post-operative discomfort.

Many investigators including Landsmann (1935), Bulatov (1950), and Levine et al. (1961) have found air ionization helpful in treating asthma. Deleanu et al. (1965) as well as others have found beneficial effects of

ionized air in the treatment of ulcers. David et al. (1960) found sedating and helpful effects from the use of negative air ions in the treatment of burned patients. Tchijevsky (1929) and Kohler (1956) found air ions useful in the treatment of respiratory diseases.

One of the interesting facets of the work performed with air ions is the lack of general acceptance of the concentration and type of air ions as an important environmental factor. As Kornblueh (1968) has commented, "After more than six decades of research in the field of artificial aero-ionization in the laboratories and in hospitals culminating in astounding results, it is surprising how little recognition this method has achieved."

Krueger (1969) in one of the latest reviews of the biological significance of air ions has warned that ultimate biological changes may result from air ion loss because the small ion content of the atmosphere is being reduced by our increased generation of air pollutants.

Textiles

The wide variability of many experimental studies with air ions may possibly be explained by the accumulation of static charges as reported in the studies of textiles and air ions. Deniker (1953) studied the therapeutic effects of fabrics made from polyvinyl chloride (PVC) and reported benefits from the wearing of clothing of this material in cases of such ailments as low back pain, sciatica, and arthrosis. Vassitch (1958) studied the effect of wearing garments of PVC and found an average increase of 16 percent in the pain threshold of persons wearing such

materials. He attributed the effects observed to the negative friction electricity produced by the fabric. Froger (1961) has reviewed the reported benefits of negative friction electricity and given values of fields as high as 66.8 electrostatic volts for PVC fiber.

Strang (1941) has shown that difficulties and losses which occurred in production in the textile industry could be correlated with changes in the ion levels of the air caused by sunspot activity. He attributed the relationship to the effects of the change in the ion levels on the handling of the materials on the looms.

Patents

A number of patents have been granted that relate to air ionization. These include five ion controllers granted to Hicks (1951, 1952a, 1952b, 1953a, and 1953b) and one granted to Cristofv et al. (1967). The Hicks' patents relate primarily to methods and techniques of ion generation while the Cristofv patent covers the establishment of a field to enhance the application of ions in an enclosed space.

Current information system literature review

As a further check on current research in air ionization, a request for information retrieval through the current research information system (CRIS) was made for all work units of research on air ions and their effects on biological systems. The results from this search disclosed that no current information on work directly applicable to air ionization was available within the system.

OBJECTIVES

The objectives of these studies have been:

- (1) To develop an experimental system and establish a procedure capable of the application and measurement of air ions that would give reproducible results.
- (2) To determine the effect of air ions on the European corn borer, Ostrinia nubilalis, using CO₂ output as an indicator of the rate of metabolism.

PROCEDURE

The hypothesis tested in this experimental work was that air ions are not an environmental factor that affects the biological systems of insects. To evaluate this hypothesis, experiments were conducted in which the adult corn borer was subjected to measured concentrations of positive and negative air ions. The CO₂ output of the insects, as determined with an infrared gas analyzer, was used to indicate changes in the rate of metabolism and activity of the insects within the environment of normal tank air and at increased ion levels.

The experimental procedure involved four major parts. These were the raising and handling of the insects, the construction of equipment and facilities, the provision of instrumentation for the CO₂ measurement, and the operation of the tests.

Raising and Handling of the Insects

To avoid wide variations in the insect characteristics because of culture background, cooperation was obtained from the United States Department of Agriculture, European Corn Borer Laboratory at Ankeny, Iowa, to supply the insects. A separate subculture was established by this laboratory from their continuous rearing cycle to provide a weekly supply of corn borers with a uniform background and characteristics.

In the normal rearing cycle at the Corn Borer Laboratory, eggs were collected from oviposition cages and incubated at 80°F and 75 percent rh for four days under continuous fluorescent light. Each larva hatching from an egg was placed in a glass vial containing a food medium. The

vials with larvae were placed in an incubation chamber for a period of 21 days, with temperature and humidity maintained at 80°F and 75 percent rh.

Cotton plugs that were used to close the open end of the vials were removed after 21 days. The vials were then placed in oviposition cages in a second incubator room where the same temperature and relative humidity were maintained along with a light cycle of 16 hours followed by 8 hours of darkness. The emerged adults mated, and the females deposited their eggs on paper discs within the oviposition cages to continue the cycle.

For the culture used in this study, the 1st instar larvae that had been placed in the vials with the food medium were brought from Ankeny at weekly intervals. The development of the larval, pupal, and adult stages was continued in an incubator constructed to provide a constant temperature and humidity at the Agricultural Engineering Research facility. A light-dark cycle of 16 hours of light and 8 hours of darkness was used to establish a circadian rhythm cycle that would allow testing under conditions of either light or darkness. The 16-hour light cycle was selected because of the information presented by Beck (1963) that indicated this would be the minimum period of light needed to obtain 100 percent pupation for a period of light exceeding 8 hours.

After approximately 20 days, the pupae within the vials were transferred to individual plastic jelly cups where they continued their development to become adults. Adults were kept in the incubator under the same environment and light cycle as the larval and pupal stages.

Emergence normally occurred during the dark cycle. The majority of the adults emerged within a two to three day period. Records were kept of

the date of emergence and the insects separated by sex so that adults of known age and sex could be used for specific tests.

Insects were transferred from the incubator to the test chamber as required. In any given test, airflow and ionization levels were adjusted and the CO₂ output of the insects monitored. A continuous flow of air carried the exhaust from the test chamber through the gas analyzer.

After each test, insects were returned to their individual container and placed in the incubator. Insects were kept under observation until they died to determine possible effects on mortality that might have been caused by ion treatment.

Temporal conditioning effects were avoided by the use of different insects for each experimental test. This eliminated the possibility that responses might be induced with no stimulus present because of the repeated introduction of ions from preceding tests.

Construction of Equipment and Facilities

General

To provide a facility suitable for making low level signal measurements and for using radioactive sources, a special laboratory area was constructed. The enclosure in which the experiments were performed consisted of a double copper screened room 10x13 feet. The screen room reduced electromagnetic disturbances to a level that allowed low current measurements.

The screen room was located in a 20x20-foot insulated laboratory room. Positive ventilation was provided by a squirrel cage blower fan.

Exhaust air was vented to the outside of the building to eliminate radioactive buildup inside the laboratory facility from the tritium sources used in the ion generators. Temperature control of the experimental area was obtained by controlling the temperature of the inlet air to the ventilation system fan.

A general view of the experimental setup is shown in Figure 1. The major components are the electrometer for air ion measurement, the insect test chamber, the ion generator, the CO₂ analyzer, the strip chart recorder, and the air supply.

A block diagram of the experimental system is shown in Figure 2 giving the relationship of the major system components.

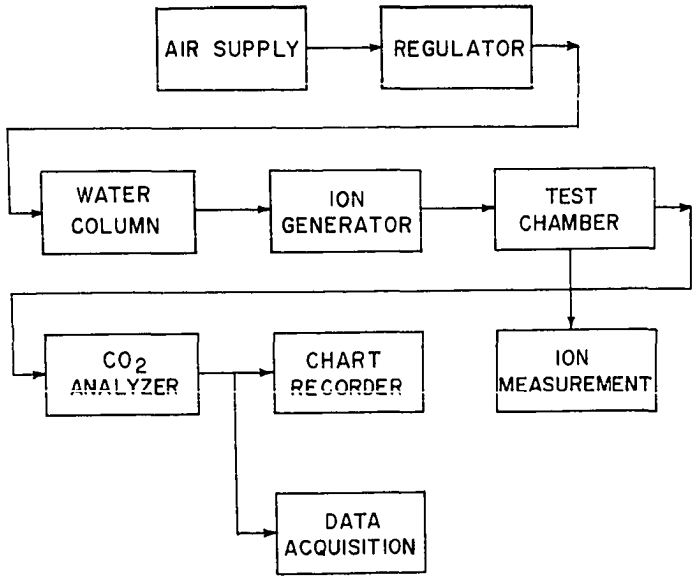
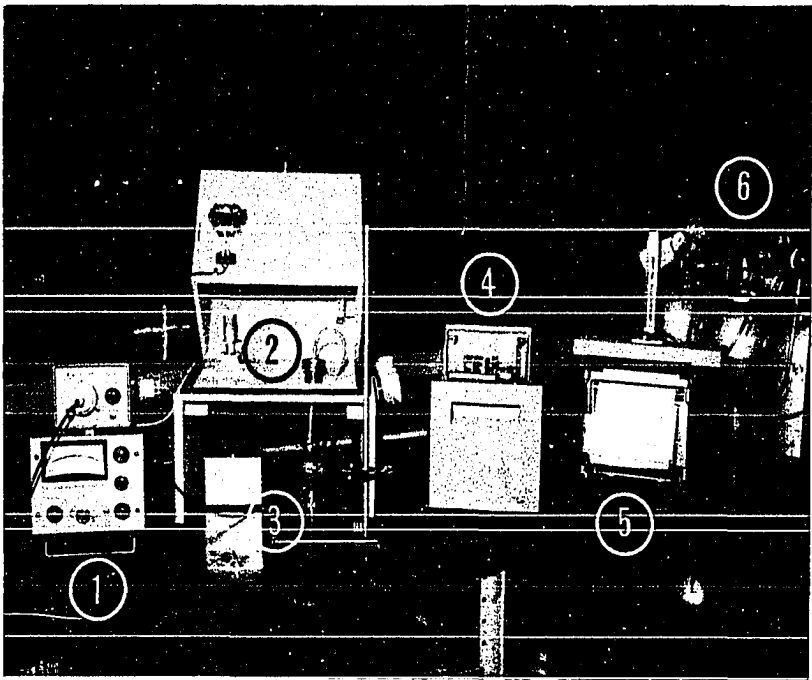
Insect incubator

To provide a suitable environment for raising the corn borer larvae and pupae, a temperature and humidity controlled incubator was constructed to maintain the insect culture received from the Ankeny Corn Borer Laboratory. Temperature within the enclosure was maintained at $80 \pm 1^\circ\text{F}$ by a solid state, phase-proportioning temperature controller using a thermistor sensing element. The humidity was maintained at 75 ± 1 percent by the control of the motor of a "cold" vaporizer type of humidifier using an electronic humidity control that was designed and constructed for this application. A Hygro-dynamics narrow range humidity element was used as the sensing element for the control. A schematic of the control circuit developed for this application is shown in Figure 3, and the humidity control unit is shown in Figure 4.

Figure 1. General view of instrumentation and test equipment

- | | |
|-----------------------------|-----------------------------|
| 1. Electrometer | 4. CO ₂ analyzer |
| 2. Insect treatment chamber | 5. Strip chart recorder |
| 3. Ion generator | 6. Air supply |

Figure 2. Block diagram of experimental system



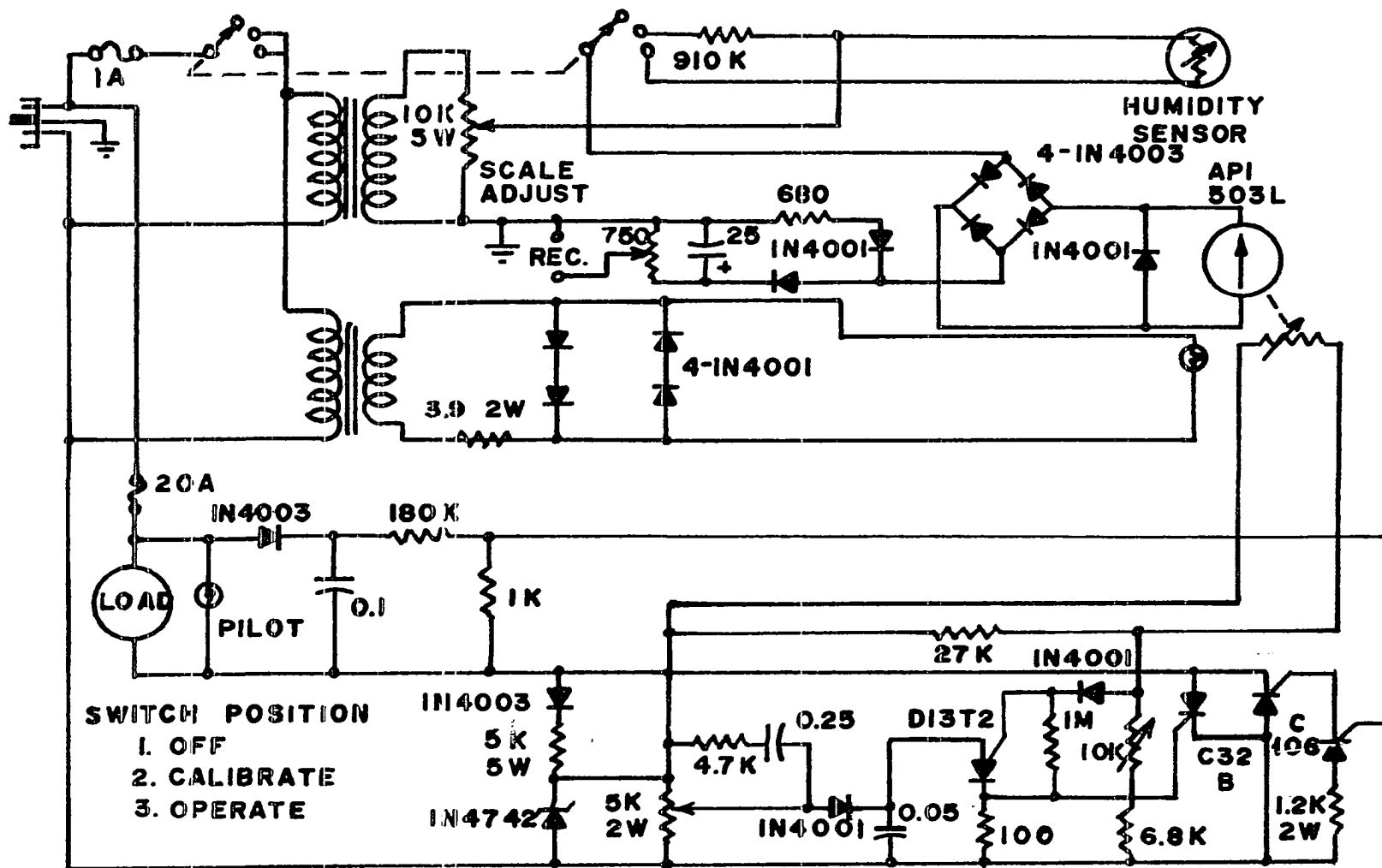


Figure 3. Humidity control schematic diagram

The heating element for the incubator was a 600-watt, 230-volt cone heater operated on 115 volts. The heater element was enclosed in an aluminum box to prevent visible radiation during the dark cycle. The inlet from the humidifier was located so that the water droplets impinged on the heating element box to vaporize the moisture introduced. Light in the incubator was provided by two 15-watt fluorescent lamps that were separated from the interior of the box by a plastic window to reduce heat input to the chamber. An electric time clock turned the lights on at 5 p.m., c.s.t., and off at 9 a.m., c.s.t.

A general view of the incubator interior is given in Figure 5 showing the trays of insects, the humidity sensor, and the heat source. An overview of the exterior is shown in Figure 6 showing the water supply and humidifier.

Air supply

Air for all tests was supplied from a tank of compressed air of breathing quality. Tank air was used to avoid the variable composition that results from using natural air.

Airflow rates for the tests were adjusted and maintained by a pressure regulator on the air cylinder. Monitoring of the airflow was accomplished with a Matheson dual-float flowmeter.

Insect test chambers

Three different insect chambers were constructed for the tests; a metal cylinder, a screen cage within a glass cylinder, and a metal grid within a glass cylinder. These chambers are shown in Figure 7. The metal

Figure 4. Humidity control unit

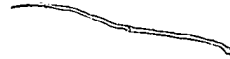


Figure 5. Insect incubator interior

1. Glass vials for larvae development
2. Plastic containers for pupae and adults
3. Humidity sensor
4. Heating element

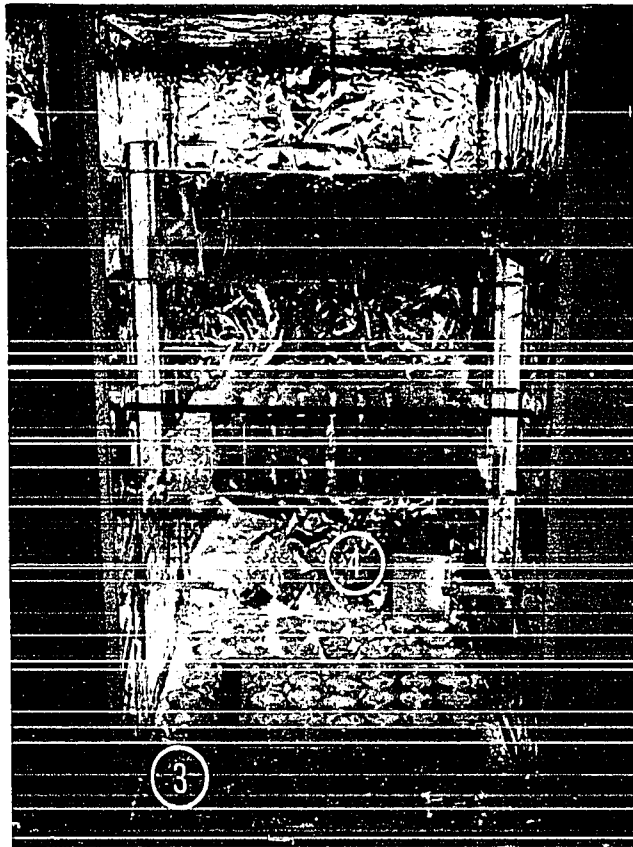
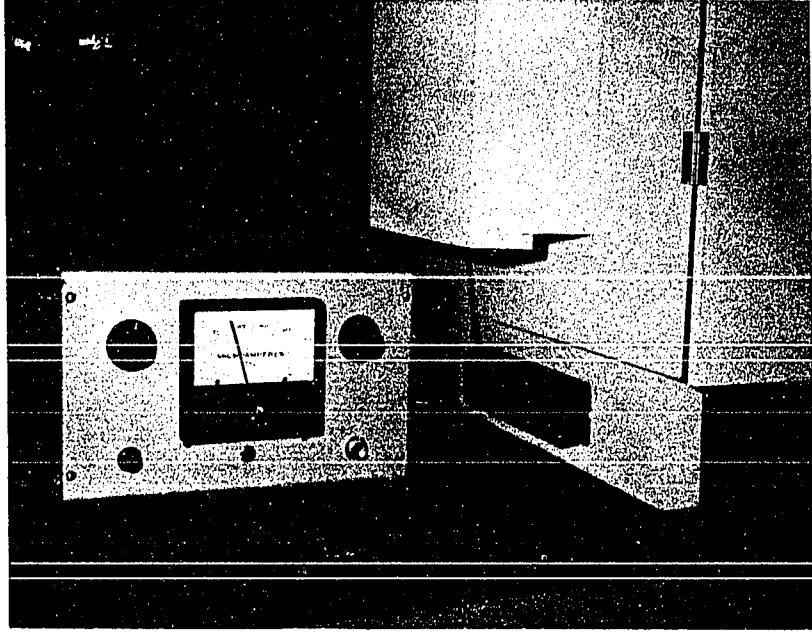
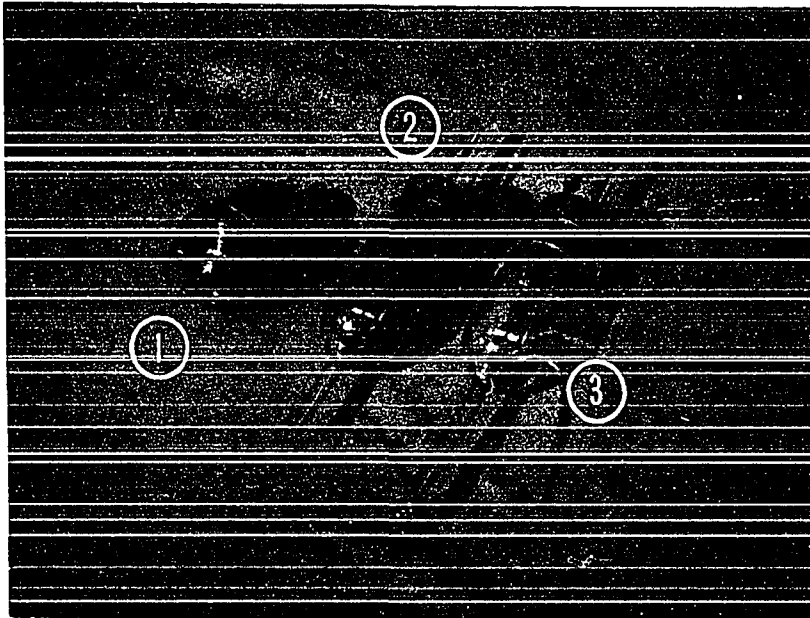
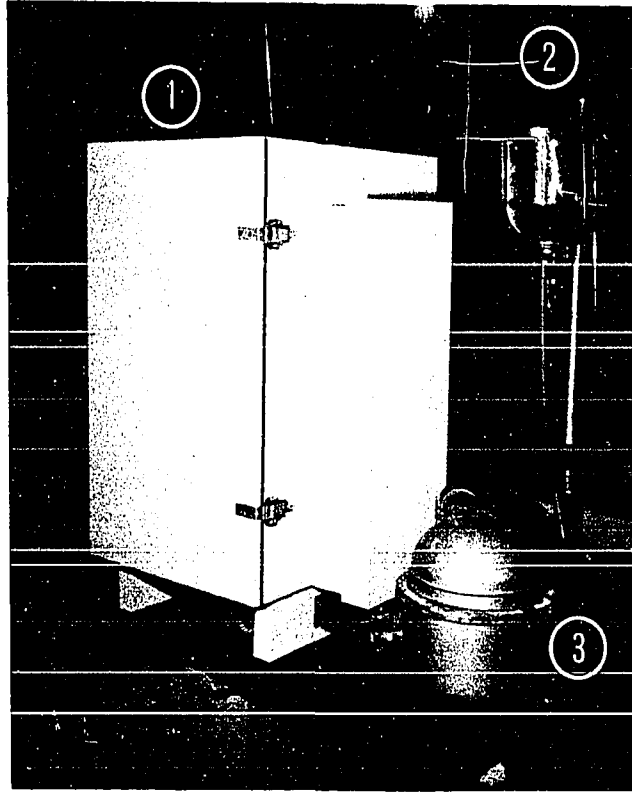


Figure 6. Insect incubator exterior

1. Insect incubator chamber
2. Water supply for humidifier
3. Humidifier

Figure 7. Insect test chambers

1. Metal chamber
2. Glass chamber with screen cage
3. Glass chamber with metal grid



chamber had the advantage of eliminating electrostatic field buildup within the test cage, but the two glass enclosures had the advantage of allowing visual observation of the insects and continuous monitoring of the ion levels.

A spun glass filter was inserted in the line between the insect chamber and the gas analyzer to remove the insect scales given off by the adults. The large quantity of scales trapped by this filter indicated that such a provision was essential to prevent contamination of the sample chamber of the analyzer.

Insect test chamber enclosure

To provide a constant environment for the insects, a special enclosure and temperature controller were constructed to maintain a closely controlled temperature during measurement of the CO₂ output of the insect. An external view of the test chamber enclosure and temperature controller is shown in Figure 8.

An air-stirring fan was provided within the chamber to improve the temperature controller performance. The fan motor was mounted externally to reduce heat input to the enclosure from the motor. A thermoelectric cooler was used to remove heat from the interior of the enclosure to allow temperature control at approximately room ambient. An internal view of the enclosure is shown in Figure 9.

Relative humidity control

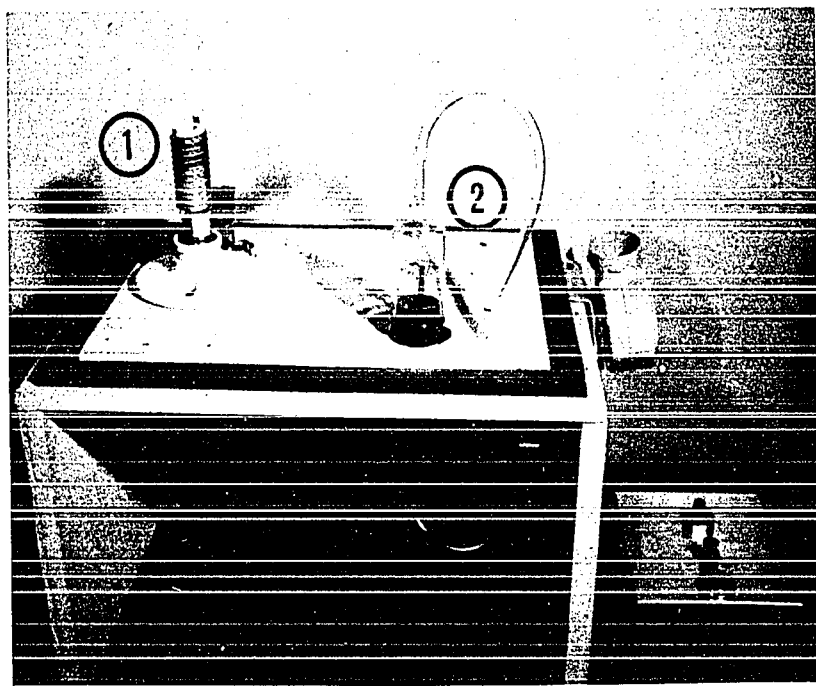
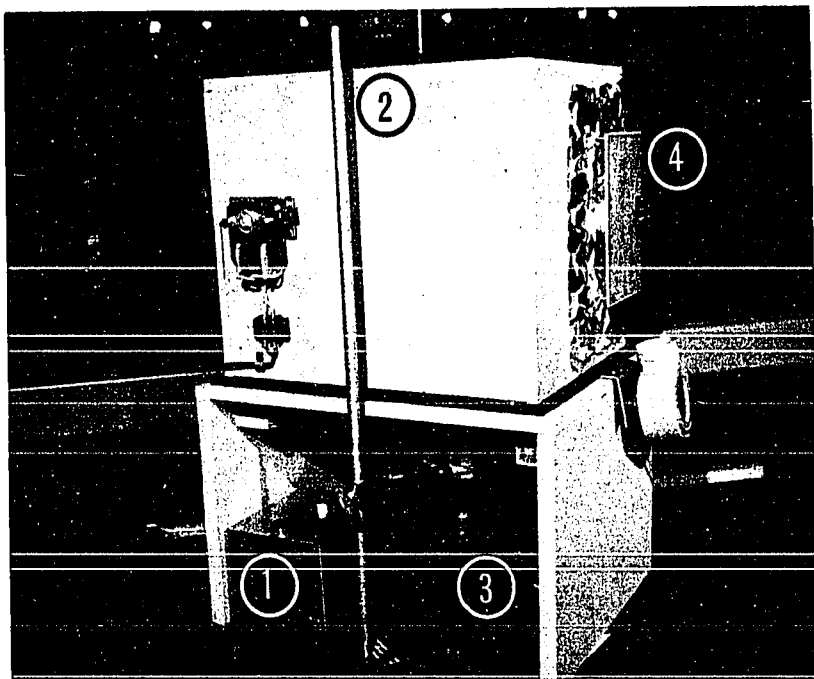
To modify the relative humidity of the tank air, the 800-liter water column shown in Figure 10 was inserted in the air supply line between the

Figure 8. Insect test chamber enclosure

1. Temperature controller
2. Insect test chamber
3. Ion generator
4. Thermoelectric cooler

Figure 9. Insect test chamber enclosure interior

1. Heater
2. Insect test chamber



air tank and the insect treatment chamber. The column was wrapped with electrical heating tape and insulated so that its temperature could be controlled by the temperature control shown at the left of the same figure. A coarse fritted glass filter was provided at the base of the column where the air entered to break the air into many small bubbles for better humidification.

The relative humidity of the air was controlled by regulation of the water column temperature with respect to the temperature of the test chamber. Measurements of relative humidity were made using the HygroDynamics, Model 15-3000, humidity measuring instrument and an appropriate narrow-range sensor mounted in the airstream in the sensor enclosure, shown at the right of Figure 10.

Ion generation

Since commercial equipment was not readily available to provide air ions, two ion generators were designed and built for creating unipolar ionization. In both units, a radioactive tritium source was used to create air ions of both polarities. Separation of the ions was obtained by air movement and the application of an electric field. Polarity of the electric field determined the polarity of the ions generated.

A radioactive source was used for ion generation to avoid unwanted biologically active components such as the ozone produced by a corona discharge generator. The output level of air ions was controlled by varying the electric field and airflow.

The radioactive foil used for the generation of the air ions was a beta emitting, titanium tritide foil, 0.5 inch by 0.5 inch on a 0.002 inch

thick, grade 302, stainless steel backing. The foil contained 250 mc of tritium (^3H).

The first ion generator constructed was a cylindrical unit as shown in Figure 11 and diagramed in Figure 12. Air introduced at the bottom of the cylinder passed by the horizontal support for the radioactive source. A separation potential was applied between the source support and the end cap to attract the desired ions while repelling the unwanted polarity. The electric field created by this potential, in combination with the movement of the air past the ionization area, produced the unipolar ionization.

The desire for greater ion output at the low airflow rates needed for CO_2 measurements led to the construction of a second ion generator. This generator was a coaxial cylinder, designed to provide a greater air velocity over the radioactive source. Figure 13 is a photograph of the generator, and a schematic diagram of the basic construction is shown in Figure 14.

Both ion generators provided unipolar ions, but the cylindrical unit was used for the tests because of its higher output.

Dessauer (1931) found a 65 percent loss in ions that were moved through a 4.6-meter tube at a flow rate of 40 cc/sec. Therefore, to prevent large ion losses at the low airflows used in these experiments, the ion generator was coupled to the insect test chamber with a minimum length of 1/4-inch tygon tubing.

Figure 10. Heated water column and humidity sensor

1. Water column temperature controller
2. Water column
3. Humidity sensor and control unit

Figure 11. Cylindrical ion generator

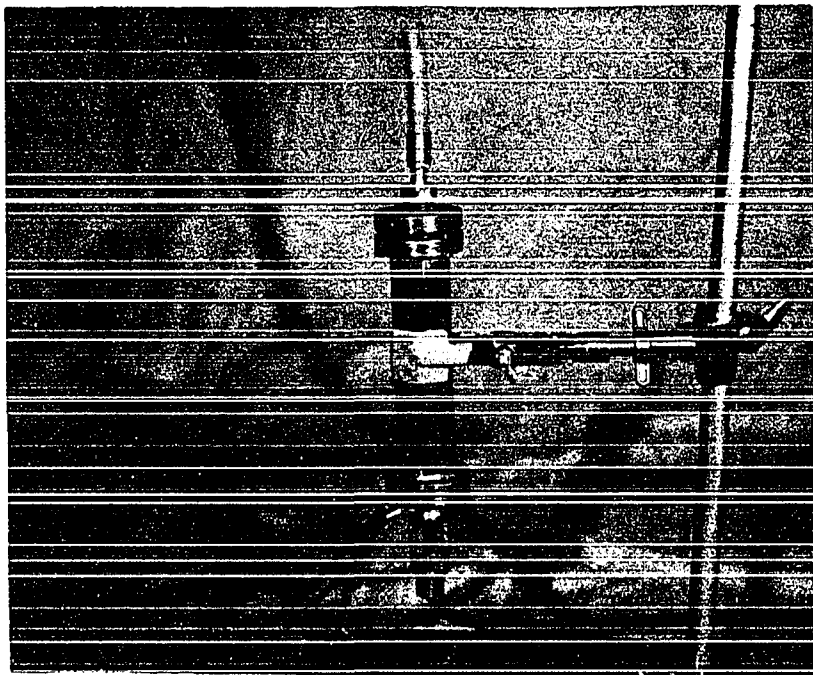
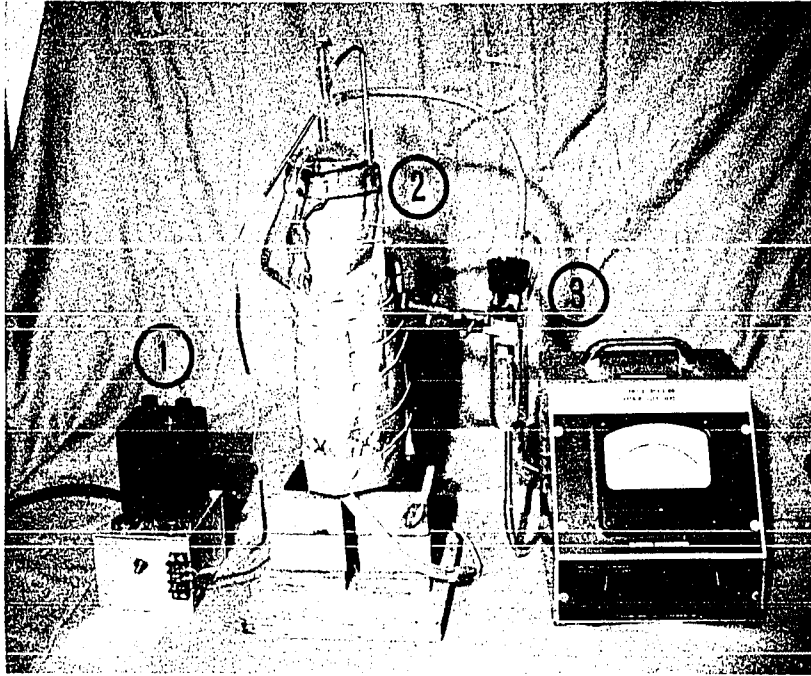
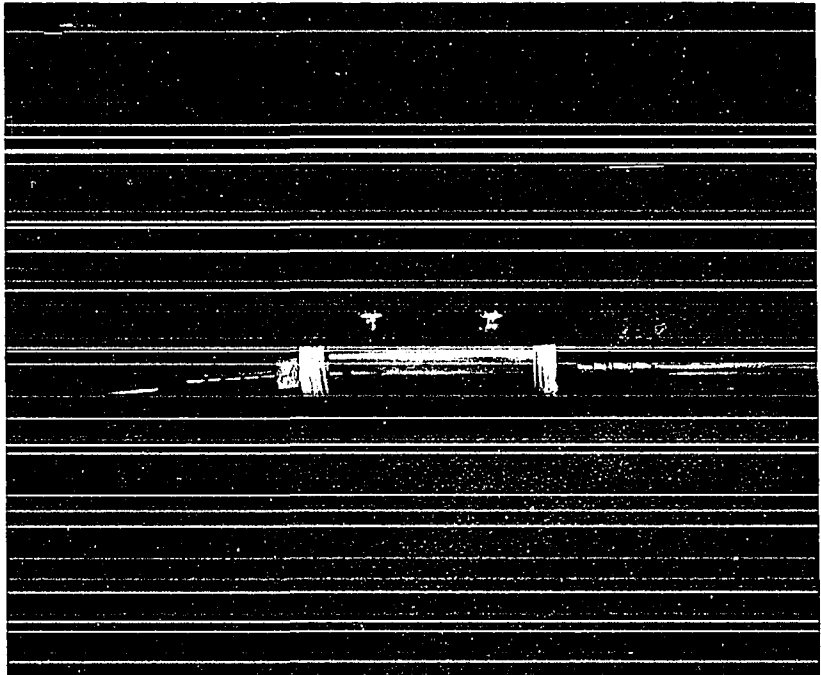
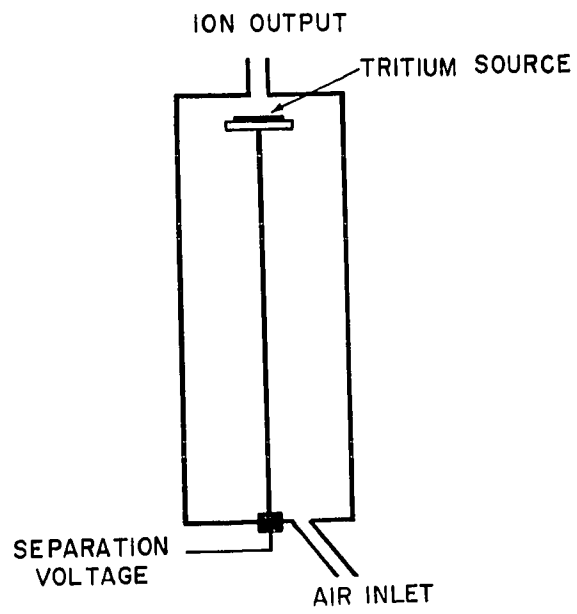


Figure 12. Schematic diagram of cylindrical ion generator

Figure 13. Coaxial ion generator



Instrumentation

CO₂ analyzer

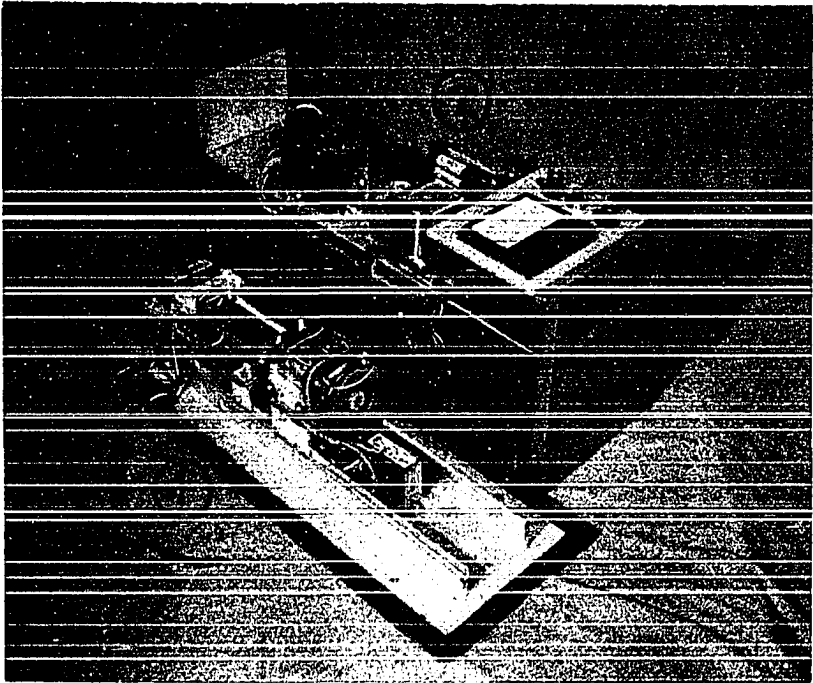
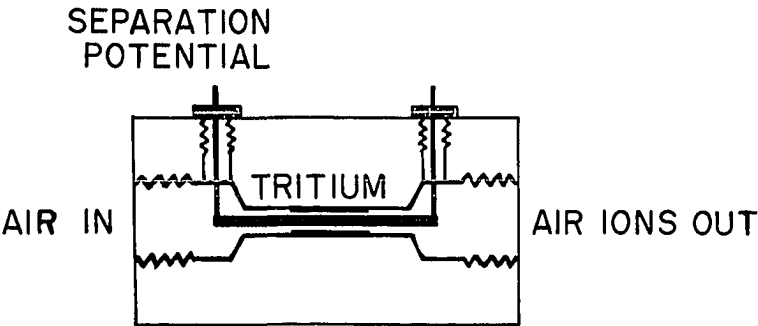
A Beckman, Model IR 215, CO₂ analyzer was used to measure the CO₂ output from the insects. The internal construction of the instrument is shown in Figure 15 with the main chassis removed from its normal location above the sample cell assembly.

The principle of operation of the instrument is based on differential absorption of infrared radiation between a reference cell filled with nitrogen, N₂, and a sample cell containing the unknown quantity of CO₂. A functional drawing of the analyzer is shown in Figure 16. Reference and sample infrared radiation, chopped at a frequency of 10 Hz, are passed through their respective cells and impinge on a gas-filled variable capacitance detector. The detector capacitance varies at the 10-Hz rate of the chopping frequency and has an average value of capacitance that changes in proportion to the difference in infrared absorption between the two cells. The variation in capacitance of the detector is used to change or modulate the resonant frequency of a tuned circuit that is supplied with a 10 MHz carrier from a crystal oscillator. Carrier amplitude containing the 10-Hz signal is therefore proportional to the CO₂ content of the sample cell. The 10-Hz signal is separated from the carrier, demodulated, amplified, and rectified by a synchronous demodulator. DC output from the demodulator is further amplified to provide a meter indication and analog output signal. This instrument, with a normal full scale indication of 600 parts/million (ppm), was capable of measuring CO₂ in concentrations as low as a few ppm.

Figure 14. Schematic diagram of coaxial ion generator

Figure 15. Internal view of CO₂ analyzer

1. Sample cells and demodulator assembly
2. Sample cell enclosure and electronics



The Beckman CO₂ analyzer was operated at a gain of twice the normal calibration level to obtain the required sensitivity for monitoring the CO₂ output of a single insect. In preliminary tests of this mode of operation, it was found that a variable level of CO₂ was introduced into the analyzer infrared cell enclosure from personnel in the laboratory room. This caused variable baseline shifts of several divisions.

To provide the steady baseline required for determining the effects of air ions on the rate of CO₂ output of the insects under resting conditions, the analyzer was modified. All openings of the enclosure containing the infrared cells were sealed with Dow Corning sealant number 3145, except that provided for the entrance of the power cable. An inlet for N₂ was provided at the rear of the case to allow purging the air within the analyzer housing.

In the modified mode of operation, with a N₂ environment for the infrared cells, baseline shifts due to changes in the CO₂ content of the laboratory air were eliminated. The stability of the analyzer was improved substantially.

Turner (1969) observed that the output reading of a Beckman CO₂ analyzer, model IR 215, was affected by the relative humidity of the test gas. To determine the effect of humidity on the model IR 215A used in these experiments, the instrument was checked for changes in indicated reading with respect to the moisture content of a test gas.

The analyzer was initially zeroed on N₂. A test gas, with a CO₂ content of 320 ppm in N₂, was then introduced into the analyzer. Gain of the analyzer was set at 200, giving a full-scale range of 500 ppm.

Relative humidity of the test gas was approximately four percent as measured on a Hygrodynamics humidity meter. The relative humidity of the test gas was then increased by passing it through a water column at 77°F.

Initial readings showed a drop in the CO₂ scale reading with increased humidity; but, with time, the reading returned to its former value. After approximately two hours of gas flow at 77.5 percent rh and 77°F, the final reading was identical to the initial reading obtained for dry gas. As a further check, air containing less than five ppm of CO₂ was run through the water column following the preceding test. A reading of 260 ppm of CO₂ was obtained. Therefore, it was concluded that the analyzer had no appreciable sensitivity to the water content of the test gas at relative humidities in the range of 4 to 77.5 percent. The reported sensitivity to relative humidity was probably an artifact caused by absorption of CO₂ by the water column used to raise the relative humidity of the air.

Ion measurement

Suitable commercial equipment was unavailable for measurement of the air ions in the insect chamber and from the ion generator. Therefore, ion measurement transducers were constructed to make these measurements. Transducer output was used for input to an electrometer to provide an indication of ion levels for this study.

Experimental measurements of air ion density were made with a "Beckett probe" and a coaxial cylinder to determine which provided the most sensitive and satisfactory measurement for the ion densities and airflows used.

The initial unit constructed was a "Beckett probe" with an effective area of 6 cm^2 as shown in Figure 17. The number of ions/cc, N , for the 6 cm^2 probe (assuming unit charge for each ion) was found from the following relationship:

$$N = \frac{I}{6qA}$$

where I = ion current in amperes

$q = 1.6 \times 10^{-19}$ coulombs

A = volume of air in cc/sec.

This "Beckett probe" was satisfactory for measurement of ion levels of 10^5 ions/cc at airflow rates of approximately 10 ml/sec. The size required for sensitivity, at lower flow rates, however, made other methods of measurement desirable.

The coaxial cylinder probe as diagramed in Figure 18 was tried and discarded after initial low current measurement showed that insulator leakage, R_I , and battery terminal to case leakage, R_B , produced current readings larger than the desired levels of current measurement. Although these leakage currents could have been reduced, it was found that the shielded coaxial cylinder shown in Figure 19 and in the cross sectional drawing of Figure 20, minimized the effects of leakage currents more effectively. The battery leakage current did not appear in the measuring circuit and the current due to insulator leakage was very small because of the almost zero potential across it as shown in Figure 21.

For the measurement of air ions by this method, the field gradient for the collection of ions is nonuniform and depends on the relative

Figure 16. Functional drawing of CO₂ analyzer

Figure 17. Beckett probe for measurement of ion concentration by ion impingement

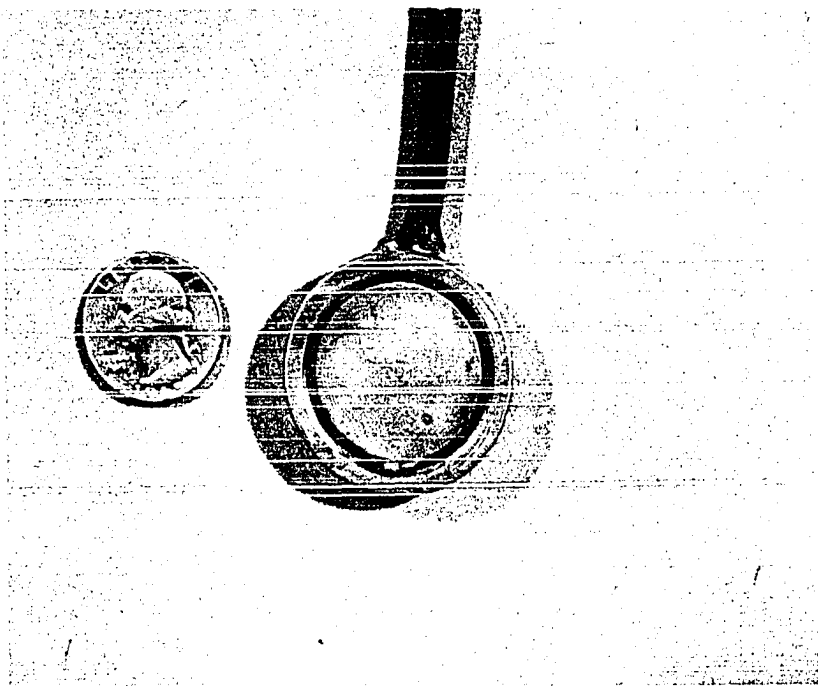
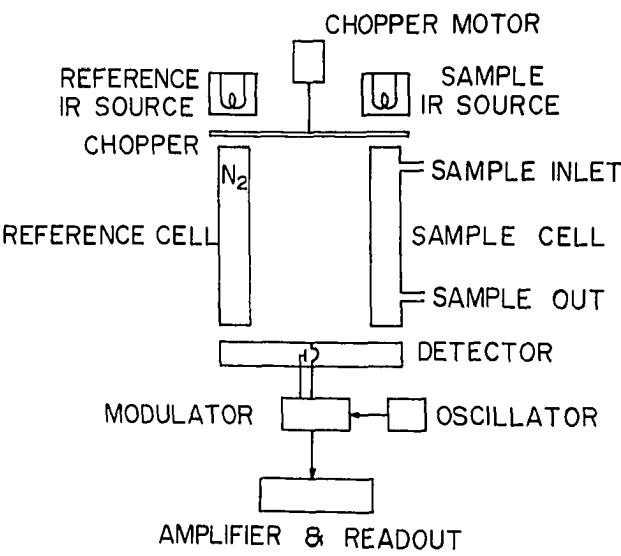


Figure 18. Leakage path diagram for simple coaxial measurement cylinder

Figure 19. Shielded coaxial measurement cylinder

1. Collector voltage source
2. Measurement cylinder
3. Ion generator

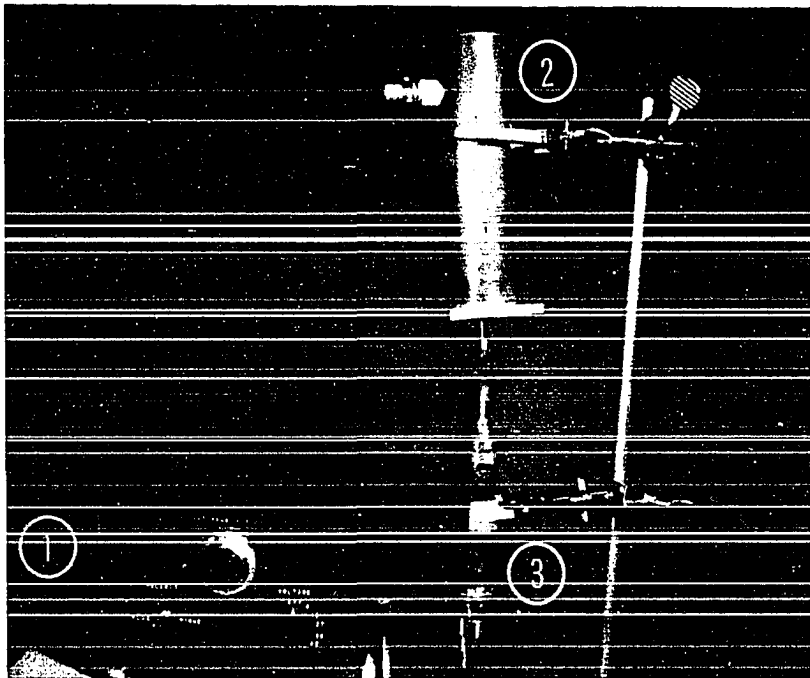
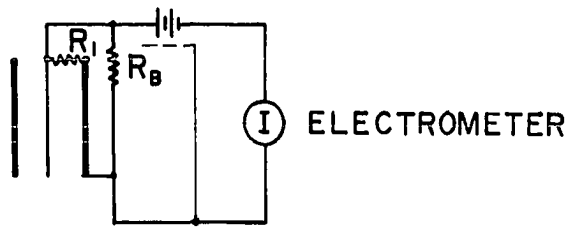
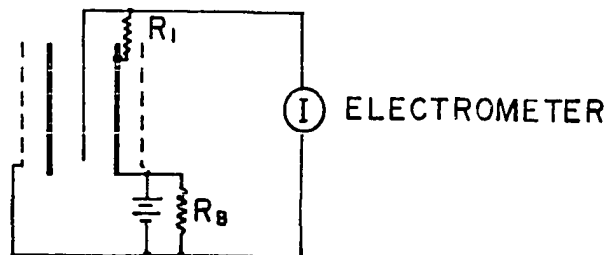
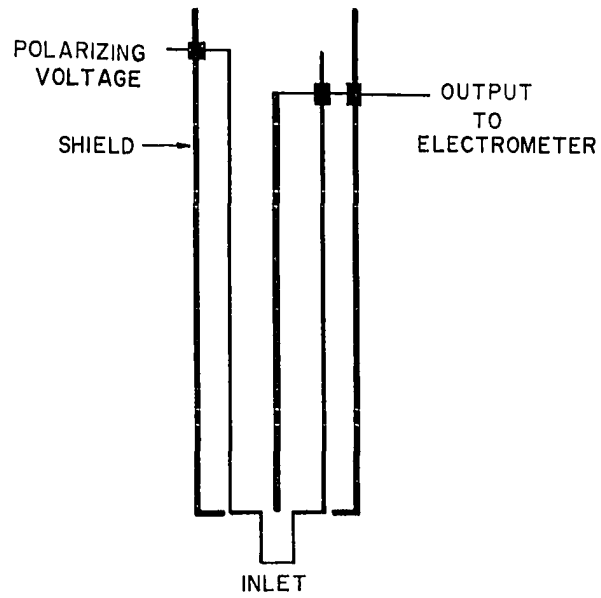


Figure 20. Schematic diagram of shielded coaxial measurement cylinder

Figure 21. Leakage path diagram for shielded coaxial measurement cylinder



diameter of the inner and outer cylinders. For the coaxial cylinder of Figure 19, calculations were made to determine the values of field strength for the two extreme surfaces within the cylinder at the outer cylinder wall and at the center rod. These values of minimum and maximum field gradient were used to estimate the effects of ion mobility on ion collection.

The value of field strength, E , for a coaxial cylinder is given by Price (1964) as:

$$E = \frac{V}{r \ln \frac{r_2}{r_1}}$$

where V = voltage applied in volts

r = distance from the center

r_2 = the radius of the outer cylinder

r_1 = the radius of the inner cylinder.

The center rod of the measurement cylinder used had a diameter of 0.238 cm, and the outer cylinder wall had a diameter of 2.143 cm. The field strength, E /applied volt, was:

$$\begin{array}{l} E/\text{applied volt} \\ \text{at the center electrode} \end{array} = \frac{1}{0.119 \ln \frac{1.072}{0.119}} = 3.82 \text{ volts/cm}$$

$$\begin{array}{l} E/\text{applied volt} \\ \text{at the outer electrode} \end{array} = \frac{1}{1.072 \ln \frac{1.072}{0.119}} = 0.424 \text{ volt/cm}$$

Calculations were also made to determine that no turbulence would be encountered for measurements made with the coaxial cylinder described in

Figures 19 and 20. Guthrie (1967) has given the air conductance of a cylinder, with no turbulence, at 20°C, in the pressure region where intermolecular collisions predominate over collisions of molecules with the tube wall, as:

$$\text{Conductance} = 0.182 \frac{D^4 \bar{P}}{L} \text{ liters/sec}$$

where D = diameter of the cylinder in cm

\bar{P} = average pressure in microns

L = length of the cylinder in cm.

For the measurement cylinder used with dimensions of $D = 2.14$ centimeters and $L = 17.8$ centimeters, the permissible airflow would be approximately 163,000 liters per second. This indicates that no turbulence would be expected within the range of airflows used in this study.

A third method for monitoring ion levels during tests used the grid of the glass insect test chamber connected directly to the input of the electrometer as a "Beckett probe." This proved to be an effective way of monitoring both the polarity and presence of the ions as well as the presence of static charges.

Measurements of the current from the test cylinder and probes were made using a Keithly, model 640, vibrating reed electrometer. A 10^8 megohm input resistor was used to give a full-scale indication of 3.0×10^{-12} amperes at a range setting of 300 microvolts.

Data acquisition system

The experimental data consisted of an analog output signal from the infrared CO₂ analyzer and the reading of ion current as obtained from an electrometer. The CO₂ analyzer output was recorded for visual observation on a strip-chart recorder and also stored on punched paper tape to provide input to an IBM 360 computer.

The strip-chart recording was made with a Leeds and Northrup, Model H, potentiometric recorder. The one-millivolt sensitivity of the recorder was matched to the 100-millivolt output of the CO₂ analyzer by a resistive voltage divider using low temperature coefficient resistors to provide a 100/1 division ratio.

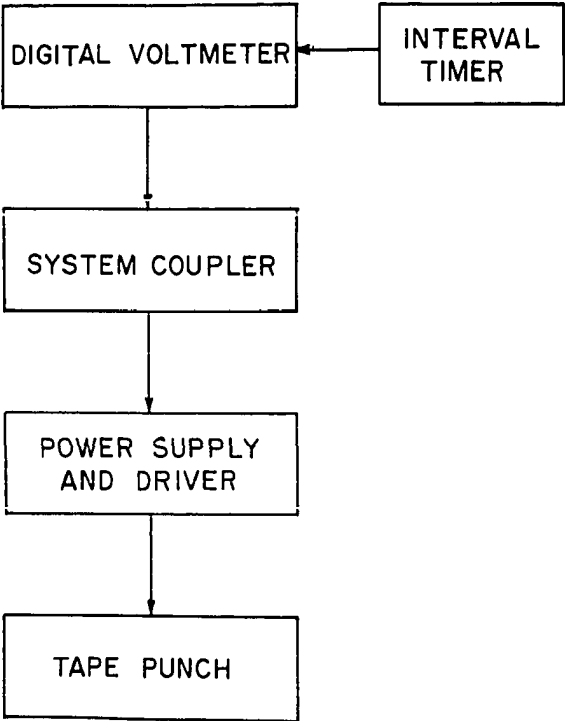
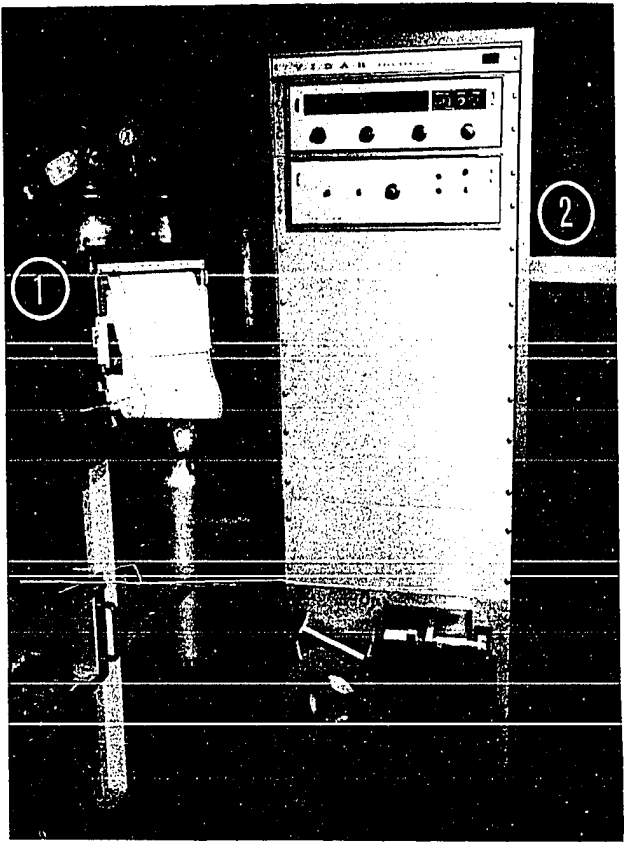
Digital data were recorded on punched paper tape with a Vidar model 5202 D-DAS data acquisition system (DAS). Components of the data acquisition system included the Vidar, Model 520, integrating digital voltmeter (IDVM), a converted Vidar, Model 653-01, system coupler modified for ASCII, the Vidar, Model P120, power supply and driver, and the Tally, Model P120, tape perforator. Figure 22 shows an overall view of the equipment, and Figure 23 gives a block diagram of the major system components.

At the command of the interval timer, the IDVM integrated the analog output signal from the CO₂ analyzer once each 30 seconds for a period of 166-2/3 milliseconds and performed the analog to digital conversion of the data signals. The binary coded decimal (BCD) output of the IDVM was converted by the coupler of the DAS to an ASCII, 8-level format, provided with a parity check, and coupled to the tape punch driver. Data

Figure 22. Data acquisition equipment

1. Strip chart recorder
2. Punched paper tape DAS

Figure 23. Data acquisition system block diagram



were encoded by the tape perforator driven by the tape punch driver. The desired data word length and format were provided by a format plug.

To conserve paper tape, the output of the data system coupler was programed to punch only three digits of the output signal. Further reduction in tape requirements was made by eliminating the algebraic sign and decimal location. These elements of information were supplied through the digital computer format statement.

The punched paper tape record from the DAS provided a digital record from the analog output of the CO₂ analyzer suitable for data input to the computer for data analysis. These data from the paper tape were entered into the IBM 360 computer through a remote conversational programing system (CPS) terminal, using a type 33 teletype.

Mathematical processing of the data was performed on an IBM 360 computer and the statistical analysis of data made by the methods outlined in Snedecor (1953) Significance of the differences in group means was determined by "t" tests and plotting of data done with the Cal-Comp digital incremental plotter utilizing a Simplotter program.

Measurement of Insect CO₂ Output

The CO₂ output of corn borer adults was determined under both resting conditions and during periods of activity using the infrared CO₂ analyzer for measurement. The analyzer was zeroed each day by passing nitrogen through the sample cell and the zero adjustment of the analyzer set to obtain zero output. Calibration and performance of the analyzer were also checked each day prior to making tests. A sample of calibration gas containing a known amount of CO₂ was passed through the sample cell

and the analyzer observed for the proper reading. Since the absolute accuracy of CO_2 was not the important criterion for these experiments, the analyzer gain was adjusted to provide a reading corresponding to the stated analysis of the test gas. The errors noted by Brown and Rosenberg (1968) that may occur in the use of an infrared analyzer for measuring absolute values of CO_2 were not considered applicable to these measurements.

During early experiments it was established that CO_2 was absorbed by the ^3H source. Therefore whenever the system accuracy was checked with the calibration gas, the ion generator was bypassed to avoid absorption of CO_2 within the ion generator. If this was not done, sufficient CO_2 was absorbed by the tritium source to give a noticeable increase in CO_2 readings in following experiments. This increased reading could not be eliminated without allowing a period of an hour or more for outgassing to occur.

A concern throughout the tests was the possible introduction of errors from CO_2 entering the system from sources other than the insects. One of the simple tests used to check for residual CO_2 in the system was that of looking for changes in baseline reading when the airflow rate was increased without insects in the test chamber. If no CO_2 was being added to the system from absorbed gas within the system components or from leaks, the reading of the analyzer remained the same. If, however, CO_2 had been absorbed or a leak was present, the reading would decrease with the increase in airflow. A decrease in reading meant that it was necessary to locate the leak or allow time for outgassing to occur so

that the system would reach a stable operating condition. In cases of outgassing, periods as long as several hours were required to achieve stability.

Tests

Tritium source effective beta energy

To aid in the design and construction of the ion generators, the effective beta energy of the ^3H source was determined experimentally. The ^3H source was placed between parallel plates and a variable separation voltage applied. Measurements were obtained for maximum ion current for both positive and negative ions.

Ion generator output

After construction of the ion generators, the ion output characteristics were determined in relation to the separation potential. The positive and negative ion output was measured over a range of separation potentials from 0 to 15 volts, using the coaxial measurement cylinder for determination of the ion output.

Flowmeter calibration

Calibration of the Matheson flowmeter used for monitoring airflow was made by comparing flow meter readings with the flow rate determined with a bubble-type flowmeter. A stopwatch was used to time the travel of bubbles through the known volume.

Air supply analysis

The air supply for all tests was obtained from a tank of compressed air. An analysis of this air was made by means of a high resolution mass spectrometer to determine the major constituents.

CO₂ output measurements of insects

Insects were exposed to air ions for two different time periods. One was a 10-minute period and the other was continuous throughout the test.

In the first series of tests, a baseline for CO₂ output was established for a single insect in a grounded metal test chamber. The ion generator was then connected in the system and positive or negative ions applied for a 10-minute interval. Following this exposure, the CO₂ output was measured without removing the ion generator from the system.

In the second series of tests, the same procedure was followed except that the ion generator was in the system only during the ion exposure period and an ungrounded metal chamber was used. The removal of the ion generator from the system eliminated the problem of CO₂ outgassing from the ³H source as experienced in the first test series, and the ungrounded insect test chamber increased the ion density within the insect test chamber.

The third series of tests were performed with continuous ion exposures to insects contained within a glass chamber. This allowed observation of the insect activity, and the test chamber configuration made continuous monitoring of ion levels possible. The monitoring period was extended to an hour before and after exposure.

System stability

To verify the test system stability, tests were run without insects to insure that the effects observed during actual tests were due to the ions and not artifacts introduced by the instrumentation system. A series of tests were run at various output voltage levels from the CO₂ analyzer corresponding to scale readings that were typical of the experiments. The data were then analyzed statistically to determine if the variation in readings over a period of time was significant so that the system stability could be established.

Measurements of ion levels were made at the beginning of each test to insure that constant ion levels were being applied.

RESULTS

Material in the following section presents data for ion generation, checks of the experimental system, and effects of air ions on the corn borer. In the first and second test series, single corn borers were given 10-minute ion treatments in a metal test chamber. Three to five insects were exposed to continuous ions in a glass test chamber for the third series tests.

Ion Generation

Effective ^3H beta energy

Initial work with ion generation was a determination of the effective beta energy available from the ^3H source used in these experiments. Measurements were made of the ionization current produced by the ^3H source placed between parallel plates as shown in Figure 24. A variable voltage

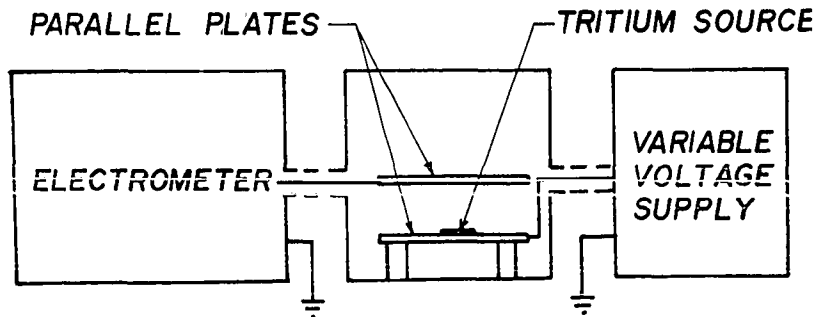


Figure 24. Equipment and instrumentation for determination of ionization current of a 250 mc ^3H source

was applied to the plates to separate the ions. Voltage was varied from 0 to 180 volts, giving voltage gradients of 0 to 320 volts/cm for the 0.56 cm plate spacing used.

Variation in positive and negative ion current with respect to the applied voltage is given in Table 1. A graph of these data is shown in Figure 25.

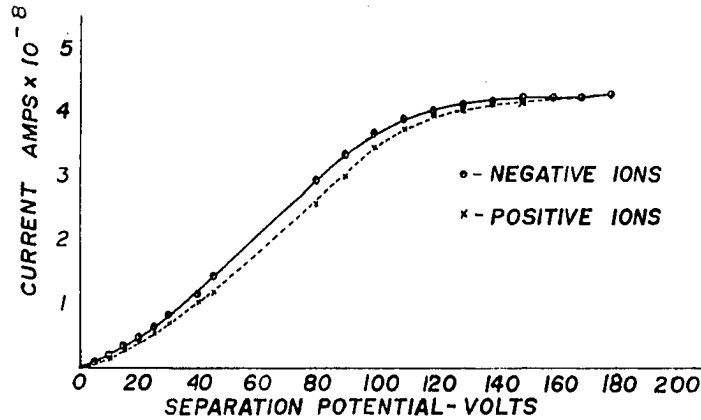


Figure 25. Ionization current of a 250 mc ^3H source vs. separation potential at an airflow rate of 1 cm/sec

The higher mobility of negative ions was indicated by greater current for negative ions at the intermediate potentials. Saturation current was 4.2×10^{-8} amperes for both positive and negative ions. This current was obtained at a separation potential of approximately 276 volts/cm for negative ions and 295 volts/cm for positive ions.

Mobility of ions, M , collected in a parallel plate collector can be expressed as follows:

$$M = \frac{d^2 v}{1V} \text{ cm}^2/\text{volt-sec}$$

where M = the mobility of the slowest ions collected in $\text{cm}^2/\text{volt-sec}$

d = the distance between the plates in cm

v = the air velocity in cm/sec

l = the length of the collector plates in cm

V = voltage applied to the plates in volts

Thus, for plates 3 cm long, 0.56 cm apart, an air velocity of 1 cm/sec, and an applied voltage of 320 volts/cm, ions having mobilities as low as $0.0003 \text{ cm}^2/\text{volt-sec}$ were collected.

By a regression analysis, data for the ^3H ionization current variation vs. separation potential shown in Table 1, were found to fit a 3rd order polynomial of the form:

$$I = a + bV + cV^2 + dV^3$$

where I = ion current in amperes $\times 10^{-8}$

V = separation potential in volts

and for (-) ions,	$a = -0.0557$	for (+) ions,	$a = -0.130$
	$b = 0.0186$		$b = 0.0310$
	$c = 0.000297$		$c = 0.000168$
	$d = -0.00000152$		$d = -0.00000118$

To aid in the design of ion generators and ionization current measurements, empirical ionization current data as obtained with the ^3H source between parallel plates were compared with theoretical values. Two approaches were used for a determination of theoretical ionization/beta from the ^3H source; Siksna's equation (1959a) and the relationships of beta energy and ion pair formation as expressed by Friedlander et al. (1964).

Siksna (1959a) has given the maximum path length of an 18.6 Kev beta

Table 1. Ionization current produced by a 250 mc ^3H foil between parallel plates with separation potential variation from 0-180 volts

Separation potential	Electrom- eter scale reading	Ion current	Separation potential	Electrom- eter scale reading	Ion current
(+) Volts	Volts	Amps x 10^{-8}	(-) Volts	(-) Volts	Amps x 10^{-8}
0	0.00	0.00	0	0.003	0.00
5	0.09	0.09	5	0.07	0.07
10	0.20	0.20	10	0.17	0.17
15	0.34	0.34	15	0.28	0.28
20	0.48	0.48	20	0.41	0.41
25	0.65	0.65	25	0.54	0.54
30	0.82	0.82	30	0.69	0.69
40	1.24	1.24	40	1.01	1.01
45	1.43	1.43	45	1.17	1.17
80	2.92	2.92	80	2.55	2.55
90	3.31	3.31	90	2.96	2.96
100	3.63	3.63	100	3.40	3.40
110	3.86	3.86	110	3.70	3.70
120	4.00	4.00	120	3.90	3.90
130	4.10	4.10	130	4.00	4.00
140	4.15	4.15	140	4.10	4.10
150	4.20	4.20	150	4.15	4.15
160	4.20	4.20	160	4.20	4.20
170	4.21	4.21	170	4.20	4.20
180	4.25	4.25	180	4.21	4.21

particle in air as 0.86 cm and the ion pair formation, IP, of the beta particle passing through one centimeter of air as:

$$IP = \frac{43}{(V/c)^2} \quad \text{ion pairs/beta/cm}$$

where V = velocity of the beta particle

c = velocity of light in free space = 3×10^{10} cm/sec

Using the relationships for conversion of voltage into velocity as given by Kaplan (1964) gives

$$\text{Velocity} = \sqrt{\frac{2E(\text{Mev})}{\text{Mass}_{\text{amu}} \times 931.141}} \times 3 \times 10^{10} \text{ cm/sec}$$

Substituting the electron mass of 5.487×10^{-4} amu and the maximum beta energy of 18.6 Kev or 0.0186 Mev gives:

$$\begin{aligned} \text{Velocity} &= \sqrt{\frac{2(0.0186)}{5.487 \times 10^{-4} (931.141)}} \times 3 \times 10^{10} \\ &= \sqrt{.0728} \times 3 \times 10^{10} \text{ cm/sec} \end{aligned}$$

And, IP, for the maximum ^3H beta energy from the Siksna equation is:

$$IP = \frac{43}{\frac{\sqrt{.0728}}{3 \times 10^{10}}} = 590.6 \text{ ion pairs/beta/cm}$$

Using values given by Friedlander et al. (1964) for an average beta energy of approximately one-third of the maximum, and a beta path length of 0.86

cm from Siksna, gives the expected number of ion pairs:

$$IP = \frac{590.6 \text{ ion pairs/beta/cm} \times 0.86 \text{ cm}}{3} = 169 \text{ ion pairs/beta}$$

The second approach for determination of ion pair formation used the value of 35 ev/ion pair and an average beta energy of one-third the maximum as given by Friedlander et al. (1964). IP yield for this relationship gives:

$$IP = \frac{\text{Av. energy/beta}}{\text{Energy required per ion pair}}$$

$$= \frac{6.2 \text{ Kev/beta}}{35 \text{ ev/ion pair}} = 177 \text{ ion pairs/beta}$$

If the required energy for formation of an ion pair of 34 ev, as given by Jesse and Sadauskis (1955), is used, the above relationship gives a value of 182 ion pairs per beta.

Theoretical current at saturation was determined from the above ion production calculations using the intermediate value of IP, 177 ion pairs/beta. By definition, one curie is 3.7×10^{10} dps and one ampere is 6.2425×10^{18} electrons per second. Therefore:

$$I_{\text{amperes}} = \frac{177 \text{ electrons/beta} \times 3.7 \times 10^{10} \text{ dps/curie} \times 250 \times 10^{-3} \text{ curies}}{6.2425 \times 10^{18} \text{ electrons/ampere}}$$

$$= 2.62 \times 10^{-7} \text{ amperes.}$$

When the above theoretical ionization current at saturation is

compared with the measured yield of 4.2×10^{-8} amperes, the empirical yield is approximately 16 percent of the calculated theoretical yield.

Differences between the theoretical and empirical values may be explained by the following losses: First, a portion of the beta energy is absorbed in the titanium foil; second, a substantial number of betas are absorbed by the stainless steel backing; and third, some ion pairs will be annihilated by recombination and absorption.

Ion generator output

Ion output of the two ion generators described in the Procedure Section was determined at separation potentials of 0 to 15 volts, and airflows of 9.7 and 15.4 ml/sec. Data were limited to this range of voltage because, at the airflows used, the coaxial unit output was reduced to zero at separation potentials above 15 volts. Ion current measurements were made at the outlet of the generator with the coaxial measurement cylinder described in Figure 19. Losses due to recombination were minimized by using a short coupling between the ion generator and measurement cylinder.

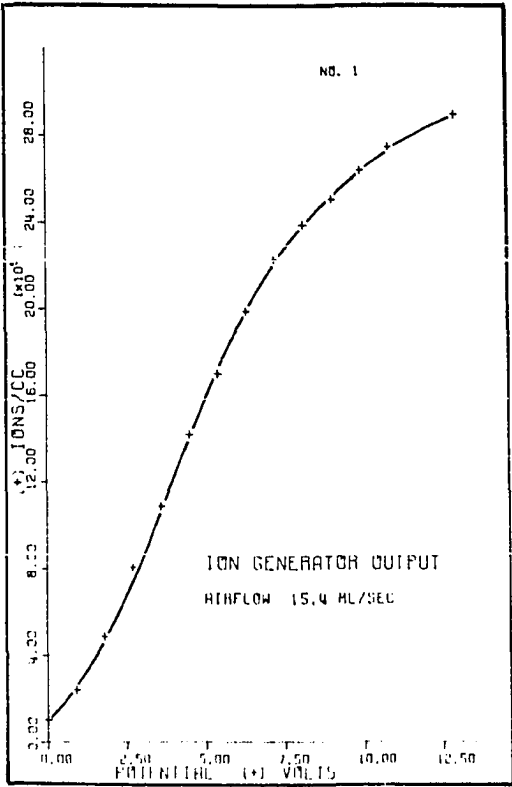
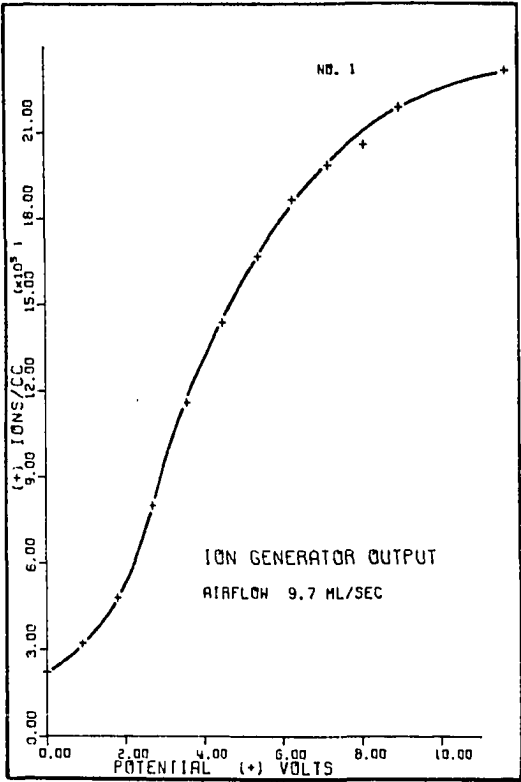
Dependence of the positive and negative ion output on the separation voltage is shown in Figures 26 to 29 for the cylindrical generator shown in Figures 11 and 12, and in Figures 30 to 33 for the coaxial unit shown in Figures 13 and 14.

Positive ion output variation for the cylindrical generator vs. separation potential is shown in Figure 26 for an airflow of 9.7 ml/sec, and in Figure 27 for an airflow rate of 15.4 ml/sec.

Maximum positive ion output of the cylindrical ion generator at the

Figure 26. Positive ion output of the cylindrical ion generator (ions/ccx10⁵) vs. separation potential for an airflow rate of 9.7 ml/sec

Figure 27. Positive ion output of the cylindrical ion generator (ions/ccx10⁵) vs. separation potential for an airflow rate of 15.4 ml/sec



airflow rate of 15.4 ml/sec was approximately 3×10^6 ions/cc, or 7.4×10^{-12} amperes. Empirical yield was .003 percent of the theoretical yield and .02 percent of the saturation current yield.

Figures 28 and 29 show the negative ion output of the cylindrical ion generator vs. separation potential for airflow rates of 9.7 ml/sec and 15.4 ml/sec.

Figures 26 to 29 show that ion output of the cylindrical ion generator for both ion polarities was sharply dependent on separation potential in the range of two to six volts. At separation potentials above 10 volts, ion output increased 20 to 30 percent for increased airflow from 9.7 ml/sec to 15.4 ml/sec and became less dependent on separation potential.

Similar data for ion output vs. separation potential are shown for the coaxial ion generator in Figures 30 to 33. Positive ion output vs. separation potential is shown in Figures 30 and 31, and negative ion output vs. separation potential is shown in Figures 32 and 33. Maximum positive ion output of the coaxial generator at an airflow rate of 15.4 ml/sec was 13×10^5 ions/cc or 45 percent of the output from the cylindrical ion generator at the same airflow rate. Maximum negative ion output of the coaxial generator at an airflow rate of 15.4 ml/sec was 5.3×10^5 ions/cc or 21 percent of the output from the cylindrical generator at the same airflow rate. Ion output of the coaxial generator has a definite peak for both ion polarities and is sharply dependent on separation voltage on either side of this peak.

Figure 28. Negative ion output of the cylindrical ion generator (ions/ccx10⁵) vs. separation potential for an airflow rate of 9.7 ml/sec

Figure 29. Negative ion output of the cylindrical ion generator (ions/ccx10⁵) vs. separation potential for an airflow rate of 15.4 ml/sec

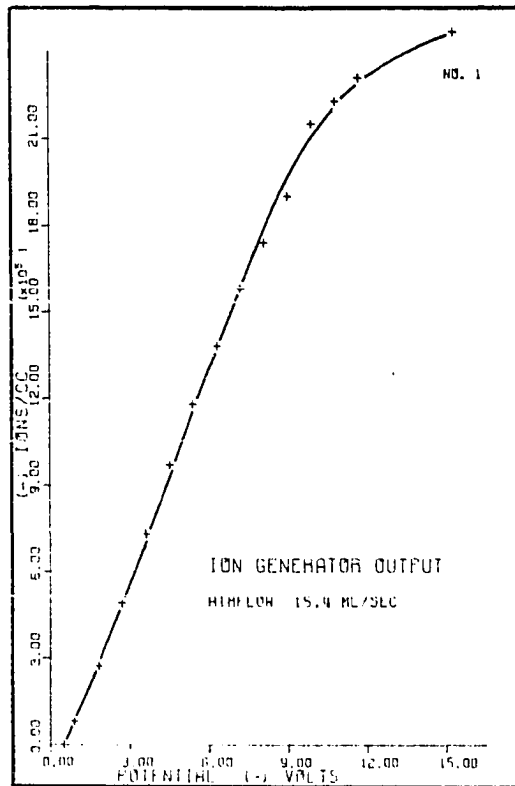
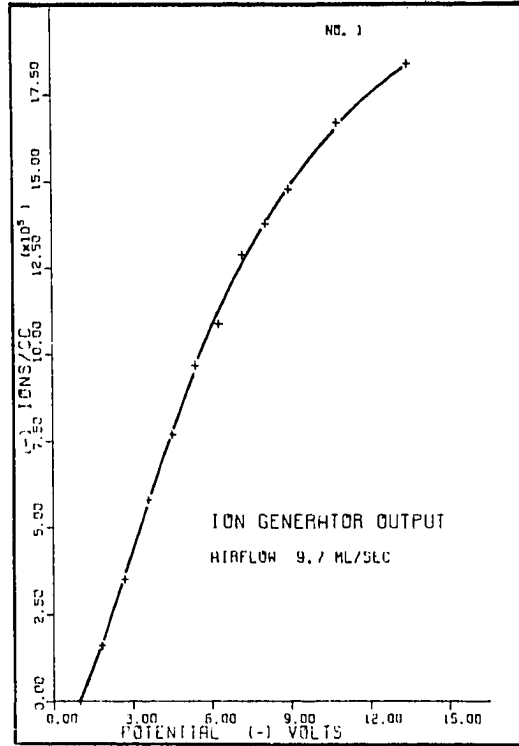


Figure 30. Positive ion output of the coaxial ion generator
(ions/ccx10⁵) vs. separation potential for an airflow
rate of 9.7 ml/sec

Figure 31. Positive ion output of the coaxial ion generator
(ions/ccx10⁵) vs. separation potential for an airflow
rate of 15.4 ml/sec

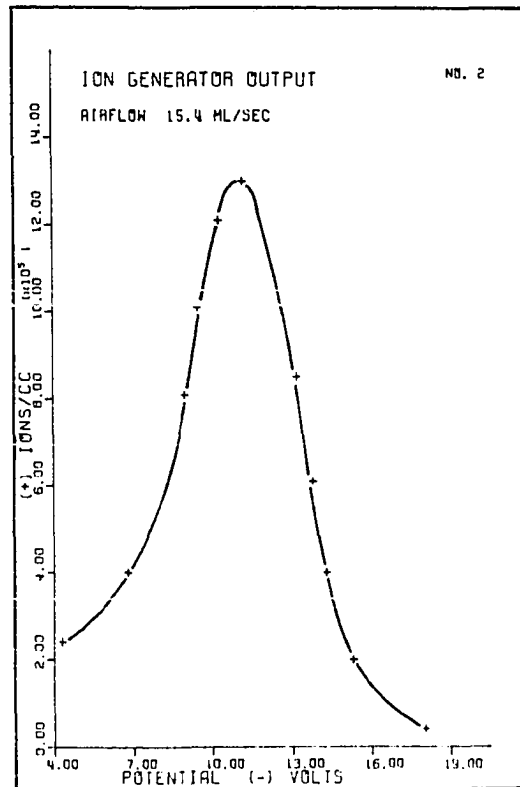
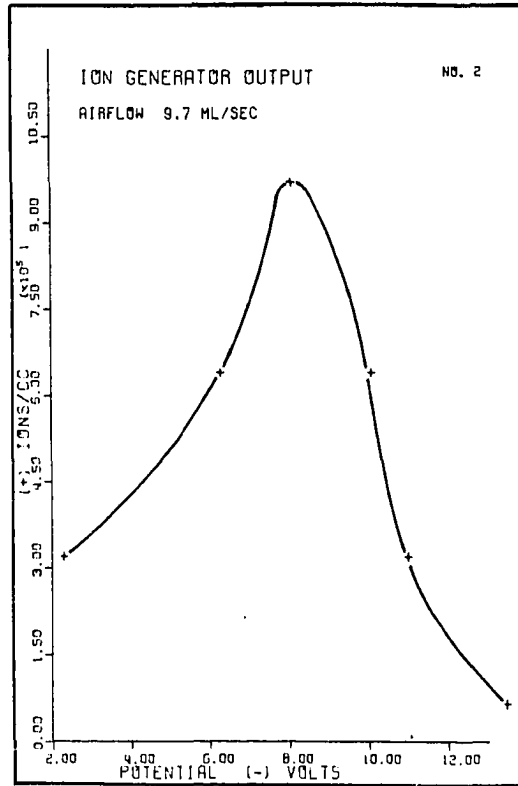
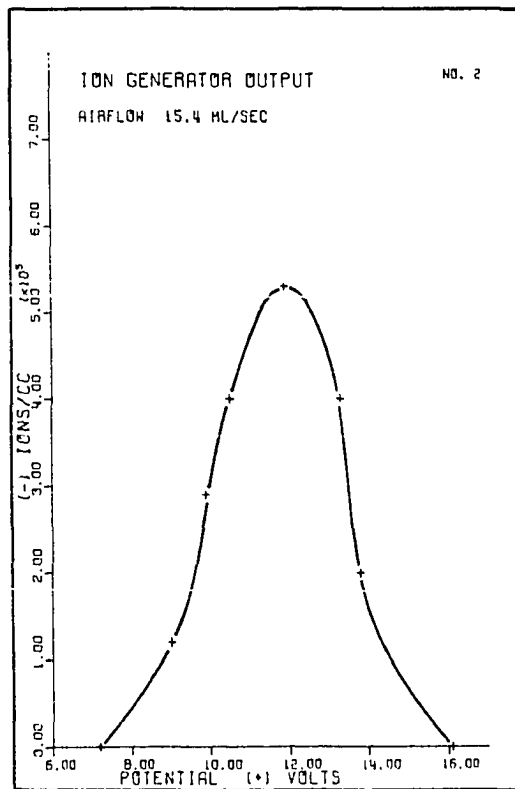
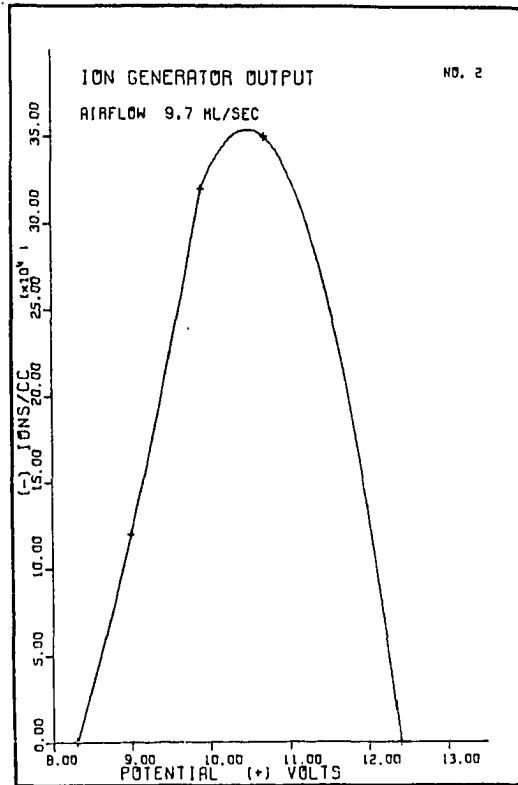


Figure 32. Negative ion output of the coaxial ion generator
(ions/ccx10⁴) vs. separation potential for an airflow
rate of 9.7 ml/sec

Figure 33. Negative ion output of the coaxial ion generator
(ions/ccx10⁵) vs. separation potential for an airflow
rate of 15.4 ml/sec



Because of the higher output and a plateau in the ion output for separation potentials over 20 volts, the cylindrical generator was used for the experiments in this study. The variation of positive ion output of the cylindrical generator with airflow over the range of 3 to 16 ml/sec is shown in Figure 34.

The mathematical relationship of ion output for the cylindrical ion generator vs. airflow was found to be a third order polynomial expression of the form:

$$I_o = a_o + A_1A + a_2A^2 + a_3A^3$$

where I_o = ion output in ions/cm³/sec x 10⁵

A = airflow rate in ml/sec

$$a_o = -6.557$$

$$a_1 = 2.577$$

$$a_2 = -0.205$$

$$a_3 = 0.00621$$

Flowmeter Calibration

Data were taken for a range of airflow rates from 1 to 17 ml/sec to establish a calibration curve for the airflow meter. A bubble type flowmeter timed with a stopwatch was used as the reference instrument. A least squares regression analysis for the flowmeter data gave an equation for the calibration curve of Figure 35 that was of the form:

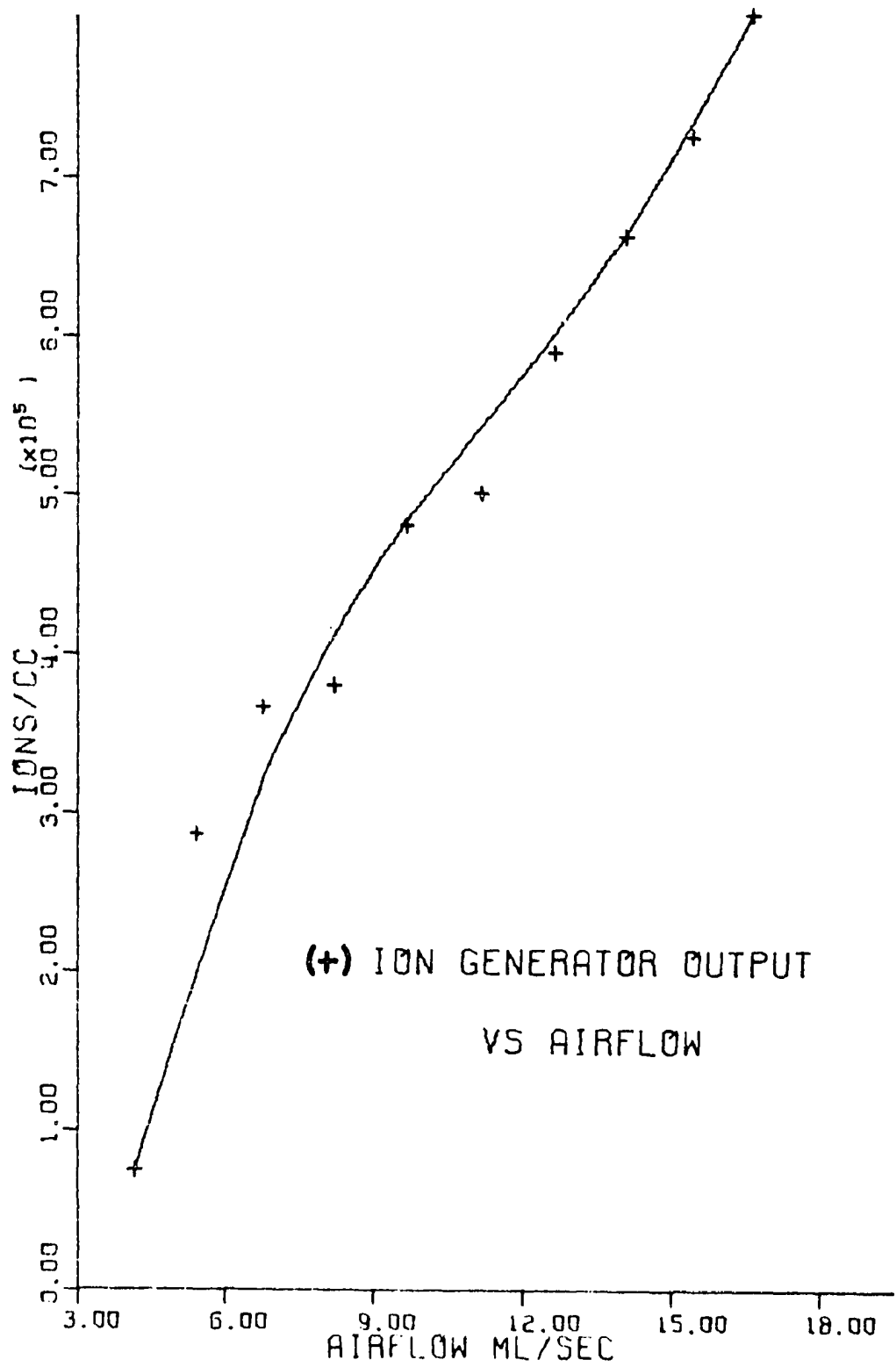


Figure 34. Ion output of the cylindrical ion generator vs. airflow rate

$$A = a + bx + cx^2 + dx^3$$

where A = airflow in ml/sec

x = flowmeter scale reading

a = 0.620

b = -0,186

c = 0.161

d = -0.00512

Air Supply Analysis

The air used for ionization and the insect environment was taken from a tank of compressed air of breathing quality. An analysis of the air was made with a high resolution mass spectrometer to determine its composition. These data are shown in Table 2 along with the normal composition of air at sea level as given by Hodgman and Holmes (1942, p. 2461).

Table 2. Composition of sea level and tank air

Constituent gas	Sea level air ppm	Tank air analysis ppm
Nitrogen (N ₂)	780,300	824,200
Oxygen (O ₂)	209,900	171,500
Argon (A)	9,400	36
Carbon dioxide (CO ₂)	300	7
Neon (Ne)	12	Not detectable

Test System Stability

To test the instrumentation and air supply stability without the presence of insects, readings of the CO₂ analyzer output were taken for each of two consecutive periods. The means for the two periods were compared statistically from data recorded at 30-second intervals on punched paper tape. The zero of the analyzer was offset to give five different scale readings corresponding to values within the range of those observed with insects at rest in the test chamber.

Data for tests comparing two 40-minute intervals are shown in Table 3 indicating the overall system stability that was obtained. Data for a similar test comparing two 10-minute intervals are shown in Table 4.

Table 3. System stability check for two consecutive 40-minute intervals

Output level scale division	<u>Means of 80 readings for each of two consecutive 40-minute periods</u>		t test
	1st period	2nd period	
2.5	2.61	2.83	9.689**
5.0	5.30	5.51	9.866**
7.5	7.59	7.75	8.002**
10.0	9.96	9.92	1.586
12.5	12.67	12.61	2.488

** Significant at 1% level.

Table 4. System stability check for two consecutive 10-minute intervals

Output level scale division	<u>Means of 20 readings for each of two consecutive 10-minute periods</u>		t test
	1st period	2nd period	
2.5	2.39	2.35	.890
5.0	4.96	4.98	.394
7.5	7.43	7.41	.476
10.0	10.15	10.16	.328
12.5	12.47	12.52	1.088

Data from Table 1 indicate that a scale reading of 10 or greater for the CO₂ analyzer output reading was required to prevent significant shifts in the means over sequential 40-minute periods. With the 10-minute intervals, as used in the majority of the tests, the system stability did not produce a significant variation in readings that would have influenced the test data at any scale reading.

Checks of major system components showed that the primary cause of system instability was the CO₂ analyzer demodulator system as discussed in Appendix B. Analyzer scale readings were reproducible at the CO₂ levels used for the tests and no contradictory results were obtained.

Ion levels at the insect test chambers were also reproducible and measurements showed that consistent levels of air ions were maintained from test to test if airflow was held constant and static charge buildup was prevented. The use of metal test chambers and antistatic coating of glass system parts effectively solved the static buildup problem.

CO₂ Output of the Adult Corn Borer

First test series

Winsor and Beckett (1958) reported definite effects of 10-minute exposures of positive ions on human subjects. Using this as a guideline, initial tests were run using this exposure period and ion polarity with corn borer adults.

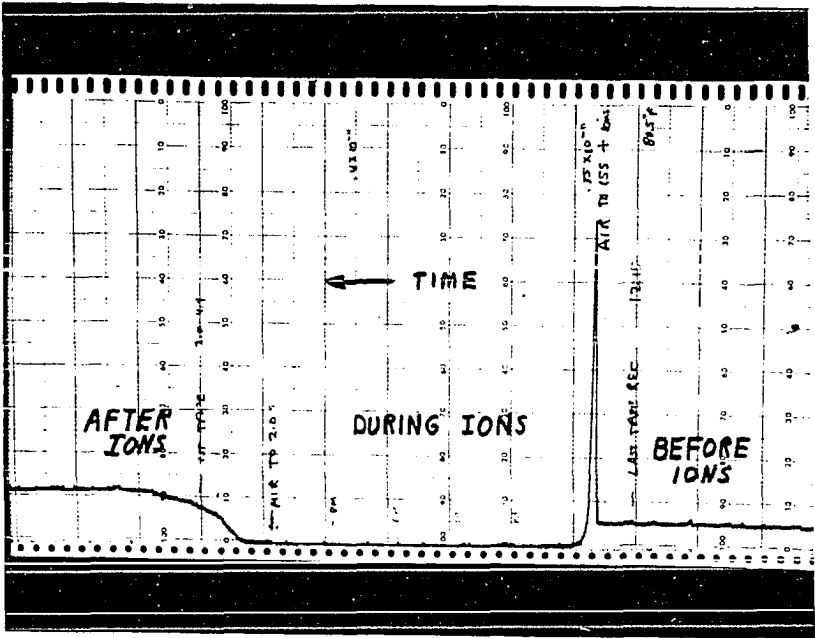
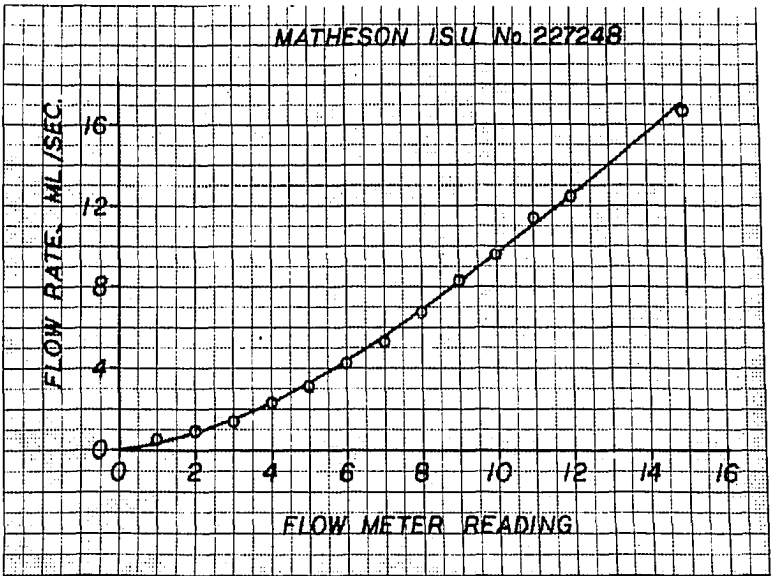
Before treating insects with ions, a baseline for CO₂ output from the insects was established with the ion generator removed from the system. The ion generator was inserted in the airstream and the insects treated with positive air ions in a grounded metal test chamber. Airflow was increased to obtain ion densities of approximately 10⁶ ions/cc at the input of the chamber for a 10-minute period. Following treatment, airflow was returned to the original flow rate and the separation potential turned off so that the ion density was reduced to the low level of the tank air.

CO₂ output of the insects following treatment was monitored at the same airflow rate used prior to ion application. An apparent increase in CO₂ output after ion application was observed as indicated in the typical test record shown in Figure 36. CO₂ level prior to the application of positive ions was approximately five divisions as compared with eleven scale divisions, after the ion treatment. A statistical analysis of this and other test data showed a consistent and significant increase in CO₂ output following application of either positive or negative ions.

Analysis of the variability of the increase in CO₂ output, however,

Figure 35. Flowmeter calibration curve

Figure 36. Chart record of CO₂ output increase due to CO₂ absorption
by ³H source of ion generator



led to the conclusion that the change in CO_2 output was not actually due to an effect on the insect but was an artifact introduced by the addition of CO_2 into the airstream from outgassing of CO_2 from the tritium source of the ion generator.

The outgassing theory was verified by tests in which no insects were present in the system and the CO_2 level was measured at various time intervals after the tritium source had been exposed to atmospheric concentrations of CO_2 . These data showed that the tritium source readily absorbed CO_2 from the laboratory atmosphere and would introduce this absorbed CO_2 into the test system when the ion generator was inserted.

When this artifact was taken into account, there was no indication of any change in the CO_2 output of the insect after positive ion exposure. It was also established that a substantial reduction of the concentration of air ions occurred because of absorption of the ions by the grounded metal test chamber. Measured concentration of air ions at the inlet of the test chamber was not representative of the actual exposure levels for the insect. Measurements using a steel ball within the chamber to simulate the insect gave a value for ion density within the chamber of 22 percent of the measured ion concentration at the test chamber inlet.

Second test series

A second series of tests was conducted with the same metal chamber as the first test series but with the ion generator removed from the system, except during the application of air ions. The test chamber was

left ungrounded except through the leakage resistance of the tygon tubing. This change increased the measured ion concentration within the insect test chamber to 59 percent of that measured at the inlet to the test chamber. Improvements were also made to hold the temperature within the test enclosure to $\pm 0.1^{\circ}\text{C}$.

A baseline for the CO_2 output of a single insect was established while the insect was at rest by a series of 10 measurements of the CO_2 output. The metal test chamber was exposed to 30°C air within the test enclosure. Airflow through the insect chamber was 1 ml/sec. At this low airflow, the insect environment was essentially at the same temperature as the test chamber.

For an ion treatment, the ion generator was inserted in the system and airflow increased to 11.9 ml/sec. Ion levels within the chamber were approximately 5×10^5 positive ions/cc for a 10-minute period. Following exposure, airflow was reset to 1 ml/sec, the ion generator removed from the system, and CO_2 output again measured as in the first determination. The statistical average of the 10 readings of CO_2 output was converted into CO_2 output/insect/hr by means of a computer program using the least squares regression equation previously determined for the CO_2 analyzer output reading. When the second test series was completed, the mean and standard deviation for each combination of age and sex were determined for comparison of the CO_2 output before and after ion exposure.

Data for the CO_2 output of the male and female corn borers before and after exposure to positive ions at levels of 5×10^5 ions/cc for the 10-minute periods are shown in Table 5. CO_2 output of the female under

Table 5. Average CO₂ output of resting adult corn borers before and after exposure to (+) ions in an ungrounded metal test chamber

Sex	Age days	No. of obser- vations	CO ₂ output (mm ³ /insect/hr.) \pm S.E.		Difference $X = X_1 - X_2$	Deviation $x = X - \bar{x}$	Deviation squared x^2
			Before ions X_1	After (+) ions X_2			
Female	1	11	82.8 \pm 3.3	73.8 \pm 4.8	9.0	3.55	12.6
Female	2	9	74.7 \pm 3.7	71.2 \pm 4.4	3.5	-1.95	3.8
Female	3	9	<u>77.7 \pm 2.1</u>	<u>69.9 \pm 2.4</u>	7.8	2.35	5.5
			$\bar{x} = 78.4$	$\bar{x} = 71.6$			
Male	1	10	51.8 \pm 3.7	46.3 \pm 2.7	5.5	-0.05	0.003
Male	2	10	39.7 \pm 2.1	36.6 \pm 2.4	3.1	-2.35	5.52
Male	3	10	<u>43.6 \pm 2.9</u>	<u>39.8 \pm 3.0</u>	<u>3.8</u>	<u>-1.65</u>	<u>2.72</u>
			$\bar{x} = 45.0$	$\bar{x} = 40.9$	32.7	0	30.2
			$s_x^2 = \frac{6.03}{6} = 1.0$	$s_x^2 = 1.0$	$\bar{x} = 5.45$		$s^2 = 6.03$
					$t = \frac{5.45}{1.0} = 5.45^{**}$		

** Significant at 1% level.

resting conditions was over 50 percent greater than that of the male, both before and after ion application. CO_2 output was also higher for both sexes on the first day after emergence as compared to the CO_2 output for the second and third days. These data are in close agreement with the preliminary data for CO_2 output of female corn borers in Appendix E.

A lower CO_2 output level was attained after positive ion exposure as compared with the CO_2 level before exposure. This decrease was statistically significant at the one percent level when the data were analyzed by means of a paired comparison t-test as outlined by Snedecor (1953, p. 44)

Tests similar to those run with positive ions were run with negative ions. Data for the negative ion tests are shown in Table 6. A depression in CO_2 output occurred after negative ion exposure, similar to that obtained for positive ions. The decrease was significant at the one percent level when the data were analyzed in the same manner as that used for the tests with positive ions.

Activity patterns of the adult corn borers varied widely with age, time of day and individuals, thus preventing a meaningful statistical comparison of activity between individual insects. Consistent and statistically different results were obtained, however, by comparing the CO_2 output of an individual insect before and after exposure to ions.

One measure of activity is the number of CO_2 output peaks per unit of time. Table 7 contains data for the activity peaks per minute for tests using individual insects in the ungrounded metal test chamber and exposed to positive ions at levels of 5×10^5 ions/cc for 10-minute periods.

Table 6. Average CO₂ output of resting adult corn borers before and after exposure to (-) ions in an ungrounded metal test chamber

Sex	Age days	No. of obser- vations	CO ₂ output (mm ³ /insect/hr.) \pm S.E.		Difference $X = X_1 - X_2$	Deviation $x = X - \bar{x}$	Deviation squared x^2
			Before ions X_1	After (+) ions X_2			
Female	1	6	69.9 \pm 2.2	62.8 \pm 1.3	7.1	2.7	7.29
Female	2	6	58.4 \pm 2.5	54.6 \pm 1.7	3.8	-0.6	0.36
Female	3	7	60.8 \pm 3.8	59.7 \pm 3.5	1.1	-3.3	10.89
			$\bar{x} = 62.7$	$\bar{x} = 59.1$			
Male	1	6	46.9 \pm 1.4	40.5 \pm 1.5	6.4	2.0	4.0
Male	2	8	52.2 \pm 3.0	48.2 \pm 3.6	4.0	-0.4	0.16
Male	3	5	59.2 \pm 1.6	55.3 \pm 1.9	3.9	-0.5	0.25
			$\bar{x} = 54.4$	$\bar{x} = 49.7$	26.3	0	22.95
					$\bar{x} = 4.38$	$s^2 = 4.59$	
$s_x^2 = \frac{4.59}{6} = 0.77 \quad s_{\bar{x}} = 0.87 \quad t = \frac{4.38}{0.87} = 5.03^{**}$							

** Significant at 1% level.

Table 7. Activity of adult corn borer as influenced by exposure to 5×10^5 positive ions/cc in the ungrounded metal test chamber

	Activity		Difference	Deviation	Deviation squared
	Before ions peak/min. X_1	After ions peak/min X_2			
			$X=X_2-X_1$	$x=X-\bar{x}$	x^2
Male					
1	0.0	3.5	3.50	1.05	1.11
2	0.55	3.0	2.45	0.00	0.000
3	0.6	2.9	2.30	-0.148	0.0218
4	0.55	2.4	1.85	-0.598	0.357
5	0.22	2.3	2.08	-0.368	0.135
6	0.5	3.6	3.10	0.653	0.426
7	0.5	2.3	1.80	-0.648	0.419
8	0.4	2.9	2.50	0.053	0.003
Total	3.32	22.9	19.58	0	2.472
Mean	0.415	2.86	$\bar{x} = 2.45$	$s^2 = 0.353$	
$s_x^2 = \frac{0.353}{8} = 0.044 \quad s_{\bar{x}} = 0.21 \quad t = \frac{\bar{x}}{s_{\bar{x}}} = \frac{2.45}{0.21} = 11.66^{**}$					
Female					
1	0.5	3.7	3.2	0.728	0.530
2	0.6	3.2	2.6	0.130	0.017
3	0.0	2.1	2.1	-0.372	0.138
4	0.3	2.3	2.0	-0.472	0.223
5	0.14	2.6	2.46	-0.012	0.0001
Total	1.54	13.9	12.36	0	0.908
Mean	0.31	2.78	$\bar{x} = 2.47$	$s^2 = 0.227$	
$s_x^2 = \frac{0.227}{5} = 0.045 \quad s_{\bar{x}} = 0.213 \quad t = \frac{2.47}{0.213} = 11.59^{**}$					

** Significant at 1% level.

A comparison of the number of activity peaks after exposure to positive ions, with that obtained before exposure, shows a significant increase after exposure at the one percent level. The difference between the number of activity peaks/minute for males was not significantly different from that of females either before or after exposure.

Increased airflow needed to produce the desired ion density for the second test series might have caused the observed change in analyzer reading either through an artifact or a change in the insect metabolism rate. To determine if increased airflow produced these effects, tests were run with insects using the exact procedure employed in the tests with ions, except that the ion generator was bypassed and no ions were introduced. Data for these tests are presented in Table 8.

Table 8. Effect of increased airflow without ions on CO₂ output of adult female corn borer

Test	CO ₂ output before airflow increase	CO ₂ output after 10 minutes of airflow at 12 ml/sec
	mm ³ /insect/hr	mm ³ /insect/hr
1	68.5	66.9
2	72.2	72.7
3	80.0	78.6
4	57.4	56.6
5	<u>52.1</u>	<u>52.6</u>
	\bar{X} 66.0	\bar{X} 65.4
	σ 11.3	σ 10.9

There were no significant differences in CO_2 output prior to the increase in airflow as compared with the CO_2 output after the increased airflow was terminated. Averages for the two cases indicated a slight decrease in CO_2 output following the increased airflow similar to that obtained in the tests with ions. This change was not statistically significant.

Third test series

In this series of tests, the metal test chamber was replaced by either a screen cage or a screen grid enclosed in a glass envelope. Initial tests established that the grid was easier to use with insects and therefore was used for the remaining tests. Measurements with a steel ball to simulate the insect within the test chamber indicated that approximately 90 percent of the ions at the chamber inlet appeared within the chamber. Monitoring of ion levels within the test chamber was accomplished using the wire grid of the test chamber as a Beckett probe. CO_2 outgassing was eliminated by leaving the ion generator in the system at all times.

A major difference between the third series of tests and the two preceding ones was the continuous exposure of insects to air ions after a baseline without ions had been established. Airflow rate for the third test series was 7 ml/sec to give an ion level of 4×10^5 ions/cc.

Tests were conducted using several corn borers at a time to raise the level of CO_2 in the airstream to readable levels on the CO_2 analyzer because of the airflow rates required to establish the ion level. Depending on their age, sex, and size, three to five insects were required for

each test.

Data were taken for a period of approximately one hour to establish a baseline for CO₂ output and activity pattern. The separation potential to the ion generator was then turned on to supply either positive or negative ions. Monitoring of CO₂ output was continued for an additional hour to determine if one or both the output level of CO₂ and the behavior pattern of the insect were modified.

Data comparisons were made between a 30-minute period immediately preceding the application of air ions and a similar period starting 30 minutes after ions were applied because preliminary tests indicated a delay in the effect of air ions. CO₂ output data for resting adult corn borers are given in Table 9. A statistical comparison of the means of the CO₂ output before and after treatment was made as outlined in Snedecor (1953, p. 44).

These data showed no significant effect of the continuous exposure of the resting adult corn borer to positive air ions as compared with the ion levels of the tank air. The after treatment mean was only slightly lower than the before treatment mean.

Other test series were run using different airflow rates and handling procedures but are not reported because the variability of the data precluded any statistically valid conclusion that a change in level of CO₂ of the resting corn borer was caused by either positive or negative ions under the stated experimental conditions.

The activity pattern of insects enclosed in the glass test chamber, however, was observed to change after ion treatments. A typical recorder

Table 9. CO₂ output of resting adult corn borers before and after continuous exposure to positive air ions in the glass test chamber

Sex	No. of insects	CO ₂ output (mm ³ /insect/hr.)		Dif- ference $X=X_1-X_2$	Devia- tion $x=X-\bar{x}$	Devia- tion squared x^2
		Before ions X_1	After (+) ions X_2			
Female	4	67.1	67.8	-0.7	-1.22	1.49
Female	4	58.8	56.6	2.2	1.68	2.82
Female	4	63.4	64.1	-0.7	-1.22	1.49
Male	5	55.9	56.6	-0.7	-1.22	1.49
Male	5	50.0	48.5	1.5	0.98	0.96
Female	4	71.6	69.4	2.2	1.68	2.82
Male	5	47.8	45.6	2.2	1.68	2.82
Male	5	52.9	54.4	-1.5	-2.02	4.08
Male	5	57.4	54.4	3.0	2.48	6.15
Female	4	<u>70.1</u>	<u>72.4</u>	<u>-2.3</u>	<u>-2.82</u>	<u>7.95</u>
Total		595.0	589.8	5.2	0	32.08
Mean				$\bar{x} = 0.52$		$s^2 = 3.56$
$s_{\bar{x}}^2 = \frac{0.52}{3.21} = 0.162 \quad s_{\bar{x}} = 0.42 \quad t = \frac{\bar{x}}{s_{\bar{x}}} = \frac{0.52}{0.402} = 1.29$						

chart trace before ion application is shown in Figure 37, and the comparable trace for the CO₂ output after positive ion treatment is shown in Figure 38. For the traces illustrated, data are shown in Table 10. A count of the number of activity peaks for successive five-minute intervals showed a mean of 10.5 peaks/interval before ions as compared with a mean of 16.5 peaks/interval after ions were applied. A statistical comparison

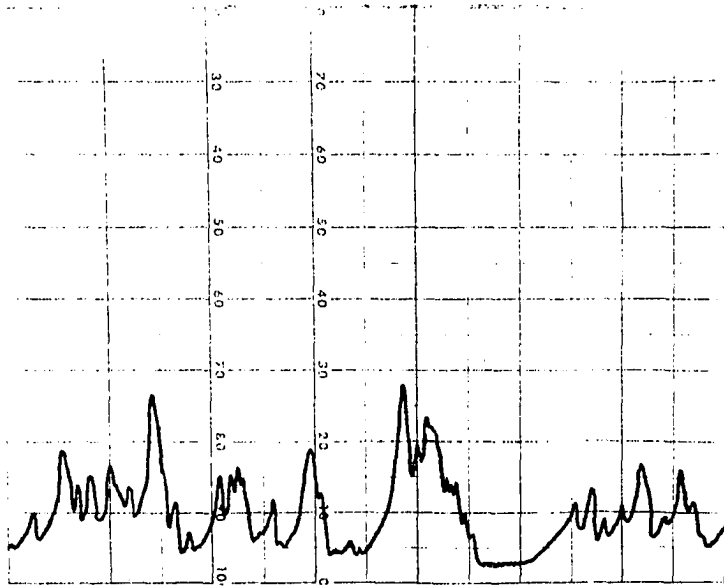


Figure 37. CO_2 output of four adult female corn borers in glass test chamber prior to continuous ion treatment

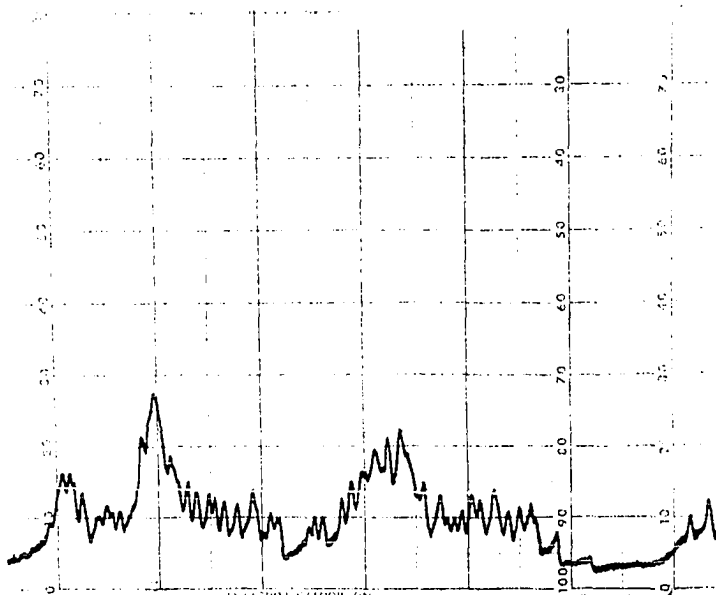


Figure 38. CO_2 output of four adult female corn borers in glass test chamber during continuous positive ion treatment

Table 10. Activity of four female corn borers in the glass test chamber

5-minute periods	<u>Number of activity peaks/5 min interval</u>		t test
	Before ions	After (+) ions	
1st	13	15	
2nd	9	17	
3rd	11	14	
4th	9	20	
	\bar{X} 10.5	\bar{X} 16.5	3.73**
	σ 1.9	σ 2.6	

** Significant at 1% level.

of the two means showed significance at the one percent level.

Another measure of the activity of the corn borers was the integral of the total CO_2 output before and after ions. The integral of CO_2 output above the resting level output is given in Table 11 and represents the CO_2 output due to activity. Activity varied widely between insects, but the data shown are representative of the values obtained. These data indicate that the total activity of the insects increased with both polarities of ionization, and this increase was generally two to four times that of the pretreatment level.

Application of negative ions, in general, produced an initial quieting effect on the insects. A greater degree of quieting generally occurred when the activity preceding the application of ions was at a high level. Prolonged exposure to negative ions, however, resulted in an increase in activity.

Table 11. Effect of ions on the activity of adult corn borers

Sex	Age (days)	No. of insects	Ion polarity	Integral of CO ₂ output above resting level (mm ³ /insect/hr)	
				Before ions	After ions
M	1	4	(+)	42.1	81.8
M	1	4	(-)	19.9	77.7
M	2	3	(-)	8.7	16.9
M	2	3	(+)	0.8	20.1
F	1	4	(+)	5.5	13.5
F	1	2	(+)	12.1	38.9
F	3	2	(-)	7.9	11.9

A typical example of air ion effects on activity is shown in Figures 39 to 41. These figures are from a continuous chart. For example, the right-hand margin of Figure 40 continues from the left-hand margin of Figure 39. Normal activity level of three adult female corn borers is shown in Figure 39. A decrease in activity occurs following application of negative ions, as illustrated in Figure 40. When positive ions were applied, the activity increased again, as shown in Figure 41.

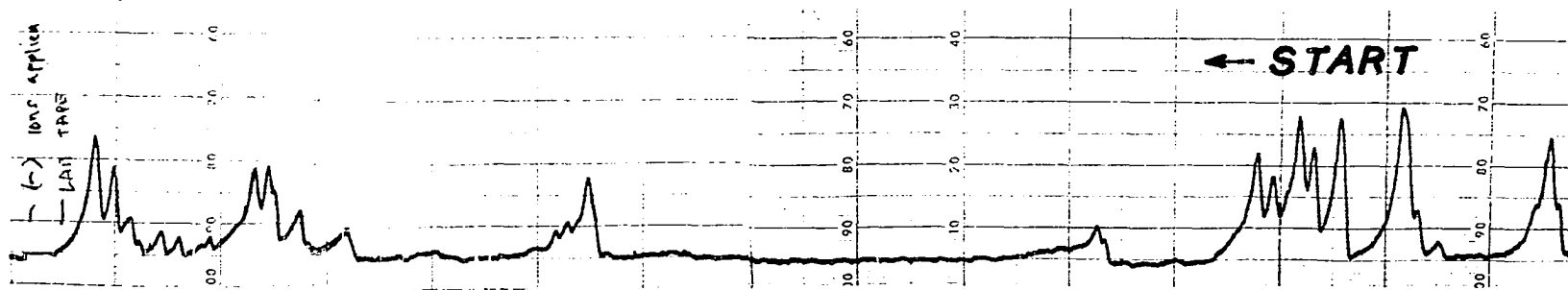


Figure 39. CO_2 output of three adult female corn borers prior to continuous ion treatment

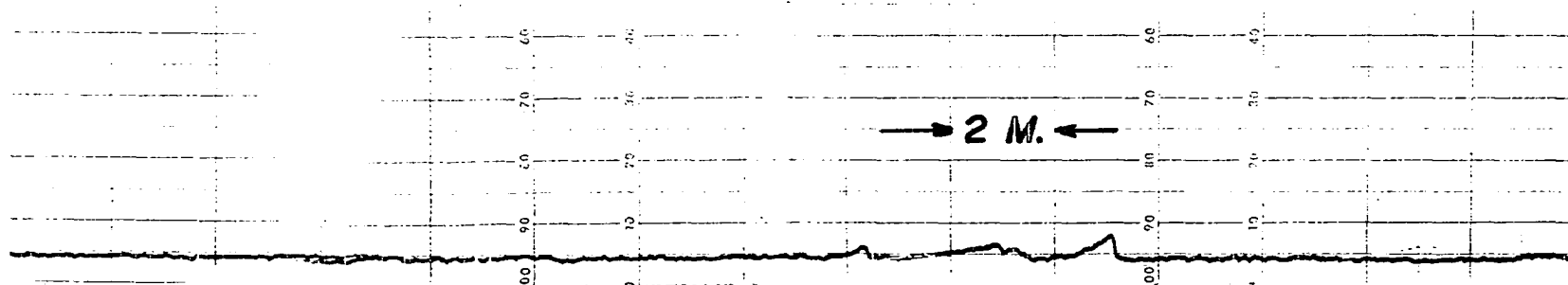


Figure 40. CO_2 output of three adult female corn borers during continuous negative ion treatment

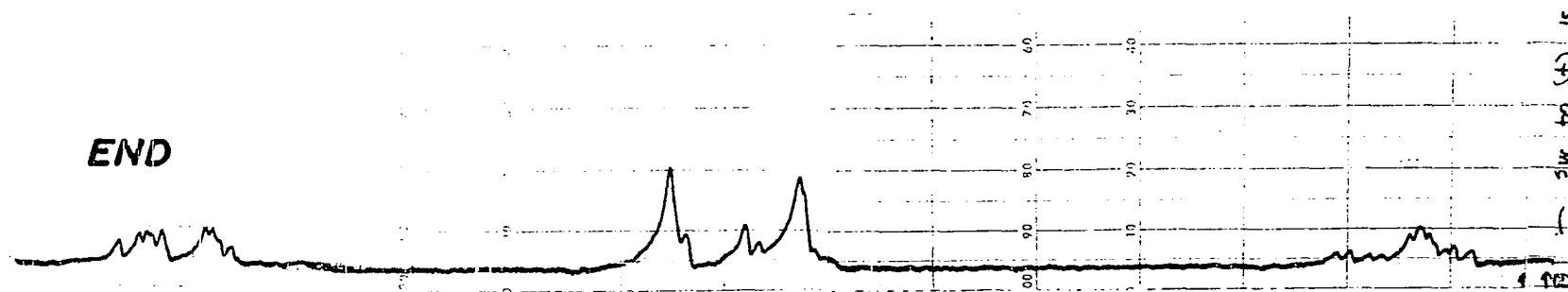


Figure 41. CO_2 output of three adult female corn borers during continuous positive ion treatment

DISCUSSION

Air ions, in the concentrations used, produced a reaction on the activity of the adult corn borer. In the opinion of the author, the ion concentrations created static electrical fields that caused the observed responses.

Statistically significant changes were obtained in the CO_2 output of resting adult corn borers subjected to positive and negative air ions in the second test series. There is a possibility, however, that the observed changes were an artifact. Another method of ion generation and a different experimental system should be used before this decrease is accepted as an effect of air ions since it does not seem logical that both polarities of air ions should have produced the same effect.

For further experiments with air ions, a change in the type of radioactive source for ion generation would be desirable. This need has been shown by the extreme care needed for the prevention of contamination from the tritium source during construction and handling of the ion generators as well as the CO_2 absorption by the titanium.

Observations made during this study have caused the author to question many of the viewpoints expressed throughout the literature; i.e., that air ions are the direct cause of the observed effects on biological systems. A careful review of the experimental results of this study and the extensive literature on the subject of air ionization has led to the following hypothesis: The effects of air ions on biological systems are caused by ion attachment to environmental elements that were previously

present in a non-ionized state. Interaction of the charge of the created multi-molecular ions with the electric fields existing within the environment gives direction and movement to the newly formed ions. Any effects on biological systems are caused by the composite ions rather than the original air ions.

If this hypothesis is valid, it may explain many of the conflicting results reported in the literature. Acceptance of this theory by researchers would also lead to a new approach in experimental work with air ions.

SUMMARY AND CONCLUSIONS

Tests were made of the effect of air ions on the European corn borer, O. nubilalis. An infrared gas analyzer was used to determine the CO₂ output of the corn borer and this output used as an indicator of the activity and rate of metabolism of the insect. An ion generator and a test system were developed and evaluated that gave reproducible test results for air ion treatments to insects.

The study led to the following conclusions:

- (1) Positive or negative air ions affect the CO₂ output of adult corn borers. Therefore, the hypothesis that air ions will not affect biological systems of insects cannot be accepted.
- (2) A unipolar ion generator with the construction of those used in this study has an output that is a very low percentage of the theoretical ion production of the radioactive source.
- (3) Continuous treatments of both the male and female adult corn borers with either positive or negative ions at concentrations of 5×10^5 ions/cc increases the rate of activity as well as the total activity.
- (4) Ten-minute treatments of both the male and female adult corn borers with either positive or negative ions at concentrations of 5×10^5 ions/cc increases the rate of activity but to a lesser degree than continuous exposures.

SUGGESTIONS FOR FUTURE STUDY

If effects of air ions on biological systems can be shown to be produced by the modification of mobility characteristics of environmental constituents rather than a biological effect, per se, new and practical applications of air ions may be made in the control of particulate matter and pathogens in all environments. The following research studies could be made to explore this concept:

1. Investigation of the mobility of ionized water vapor subjected to fixed electric fields in a confined space.
2. Studies of the size, density, concentration and other characteristics of particulate matter in environmentally controlled livestock structures.
3. Development and test of an air ion generator suitable for use in livestock structures for the control of dust and airborne pathogens.
4. Development of a practical method utilizing ionization for the control of dust and airborne pathogens in livestock structures.

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APPENDIX A:
CALCULATION OF AIR IONIZATION FORMATION RATES
AND VARIATIONS FROM BACKGROUND RADIATION DATA

Air Ionization Formation

The contribution of background radiation to the degree of air ionization was calculated using the data of Dudley (1959) and Eisenbud (1963) for natural radiation levels at the earth's surface. These calculations were used to determine the expected rate of production and levels of air ions that might be found in a typical insect environment.

An evaluation of data from the above sources indicates that a total radiation figure of 100 mrad/year is a representative average for most locations. The energy available for ion formation therefore would be:

$$\frac{100 \frac{\text{mrad}}{\text{yr}}}{3.1536 \times 10^7 \frac{\text{sec}}{\text{yr}}} \times 1 \times 10^{-1} \frac{\text{ergs}}{\text{mrad-gm}} \times 1.293 \times 10^{-3} \frac{\text{gms}}{\text{cc(air)}}$$

$$= 41 \times 10^{-11} \frac{\text{ergs}}{\text{sec-cc}}$$

The required energy for the formation of an ion pair is:

$$35 \frac{\text{ev}}{\text{ion pair}} \times 1.6021 \times 10^{-12} \frac{\text{ergs}}{\text{ev}}$$

$$= 55.6 \times 10^{-12} \frac{\text{ergs}}{\text{ion pair}}$$

and the number of ion pairs formed will be:

$$\frac{41 \times 10^{-11} \frac{\text{ergs}}{\text{sec-cc}}}{55.6 \times 10^{-12} \frac{\text{ergs}}{\text{ion pair}}} \approx 7.4 \frac{\text{ion pairs}}{\text{sec-cc}}$$

When the average ion production rate from cosmic rays of 2.2 ions/cc as given in the data of Lowder and Solon (1956) is added, the resultant ion production would be 9.6 ions/cc/sec. This gives good agreement with the statements of Hansell (1961) and Swan (1961) that the production of air ions is approximately 10 ion pairs/cc/sec and indicates that a good estimate of the rate of ion production may be made when background radiation levels are available.

Ion Level Variation

Davis and Speicher (1961) observed diurnal variations in the air ionization levels in their measurements for Philadelphia, Pa. They reported variations in mean daily levels of about 140 ions/cc. It is of interest to compare their reported variations with radon variations. Taking a mean level of radon as given by the United Nations Report (1958) of 20×10^{-14} curies/liter, the activity level would be:

$$20 \times 10^{-17} \frac{\text{curies}}{\text{cc}} \times 3.7 \times 10^{10} \frac{\text{Disint.}}{\text{curie-sec}} = 7.4 \times 10^{-6} \frac{\text{Dist.}}{\text{sec-cc}}$$

Radon gives two alpha particles:

$$4.777 \text{ Mev. (94.3 percent)}$$

$$4.589 \text{ Mev. (5.7 percent)}$$

and therefore:

$$7.4 \times 10^{-6} \frac{\text{Disint.}}{\text{sec-cc}} \left[.943(4.777 \times 10^6) + .057(4.589 \times 10^6) \frac{\text{ev}}{\text{Disint.}} \right]$$

$$\approx 35.3 \frac{\text{ev}}{\text{sec-cc}}$$

$$\text{and } 35.2 \frac{\text{ev}}{\text{sec-cc}} \approx 1 \frac{\text{ion pair}}{\text{sec-cc}} \quad \text{from Radon}$$

$$\frac{35 \frac{\text{ev}}{\text{ion pair}}}{\text{ion pair}}$$

Hansell (1961) and Swan (1961) indicate that the normal state of our atmosphere is such that an ion content of 800 to 1000 ions/cc results from a production rate of 10 ions/cc/sec. The ratio of ion level to ion production is 100 to 1. The calculated production rate of ions of one ion pair/cc indicates an average ion level of approximately 100 ions/cc due to radon.

Blifford et al. (1952) reported hourly variations of the radon and thoron content of outdoor air. Their data show a minimum concentration in the early morning hours and a maximum in the late afternoon. The peak afternoon value was approximately twice the morning minimum.

Blifford's data showing a two to one variation in radon content of air indicate that the ion levels of the air would vary approximately 100 ions/cc due solely to the variation in radon content. A minimum level in the diurnal variation of ion levels would also be expected in the early morning hours. This correlates closely with the observations of Davis and Speicher (1961) where they found a variation of approximately 140 ions/cc and a minimum level at approximately 3 to 4 a.m.

APPENDIX B: EXPERIMENTAL PROBLEMS

The problems and experiments that were performed to arrive at a workable system have not been emphasized in the preceding material covering the procedure used. There were, however, a great number of experiments required to arrive at a repeatable indication of ion effects.

Some of the problems that were encountered are described to indicate the types of difficulty that are associated with the experimental investigation of air ion effects. These examples may offer a partial explanation of the variability and conflicting results reported by other experimenters.

Charge Buildup

One of the observations that had an important bearing on early results was the complete stoppage of ions by a section glass tubing used for the conduction of air ions from the air ion generator to the measurement cylinder.

In the experimental system, ions from the ion generator were passed through both glass and tygon tubing to the insect chamber. Measurements of the output air from the test chamber under some conditions showed no appreciable number of ions and further checks were initiated to determine the cause of the sharp drop in ion levels. It was found that whenever the glass link in the tubing system was inserted, ion flow was reduced to a negligible value except at an air velocity of greater than 20 ml/sec. Further checks showed that both the glass tubing and rubber stoppers had developed electrostatic charges that essentially prevented ion transport

at the low air velocities used. These findings led to the modification of the ion delivery system by elimination of non-conducting paths for air flow. This helped insure that the expected ion levels were actually delivered to the insects and emphasizes the necessity of avoiding electrostatic buildup from the charge on the ions.

The magnitude of charge buildup was evaluated by means of a Victoreen model 5051 proximity voltmeter. This instrument allowed accurate measurement of charge buildup without contact to surfaces by means of a capacitance pickup that "floated" at the same value of potential as that of the surface being measured.

A typical static charge buildup along the glass treatment cylinder caused by the application of positive ions at levels of 0.5×10^5 ions/cc for five minutes is shown in Figure 42.

To reduce these effects and allow the use of glass within the treatment system, two methods were used: First, after startup of the system, a high relative humidity was supplied to the treatment chamber which resulted in the elimination of the charge after 20-30 minutes. Second, the rubber stopper and the glass components were treated with anti-static compound which led to a rapid dissipation of charges which occurred when the system was assembled.

CO₂ Analyzer

After a period of operation of the Beckman IR analyzer at higher than normal sensitivity, the output trace became erratic. Since statistical treatment of the data required a high degree of stability, it was

necessary to re-establish the operating performance.

It was determined that the main cause of the problem was the synchronous demodulator used for the recovery of the signal information. The closure of two reed switches was actuated by a rotating magnet attached to the chopper shaft to produce synchronous rectification. Output signals from the phase inverter were switched over each 180-degree portion of the input cycle to obtain a full wave rectified output. The actual output from the demodulator as taken from an oscilloscope is shown in Figure 43 showing a typical output trace. This illustrates both the inexactness of the switching point and the erratic switching point which occurred because of the variation in closure time of the magnetic switches. The unstable baseline produced because of these variations is illustrated in Figure 44, showing a typical chart record which occurred after a new analyzer had been in operation for a period of approximately two months.

Although the switching cycle was adjustable, there was an interaction between adjustments of the two magnetic paths. The lack of precise closure of the reed switches also made adjustment of the switching difficult at the high gain used. In an attempt to improve performance a solid state demodulator was designed using photo-transistors and reed relays as illustrated in Figure 45. The completion was too late, however, to be effectively used in the experimental work but preliminary tests indicated that an improvement in stability could be obtained by this revision.

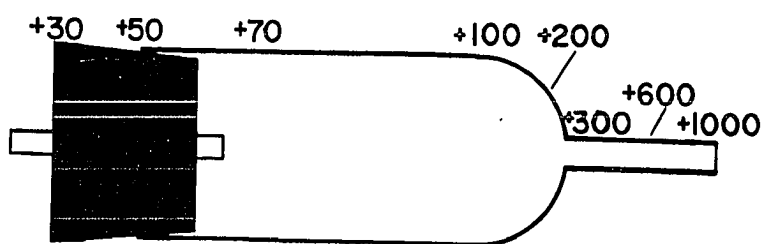


Figure 42. Static charge buildup on glass treatment chamber from positive ions

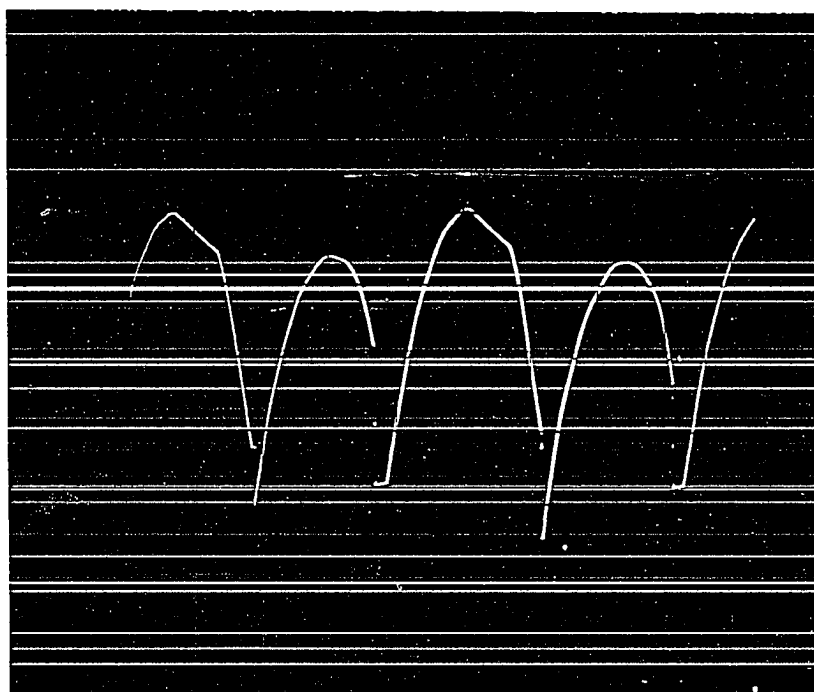


Figure 43. CO₂ analyzer demodulator output trace

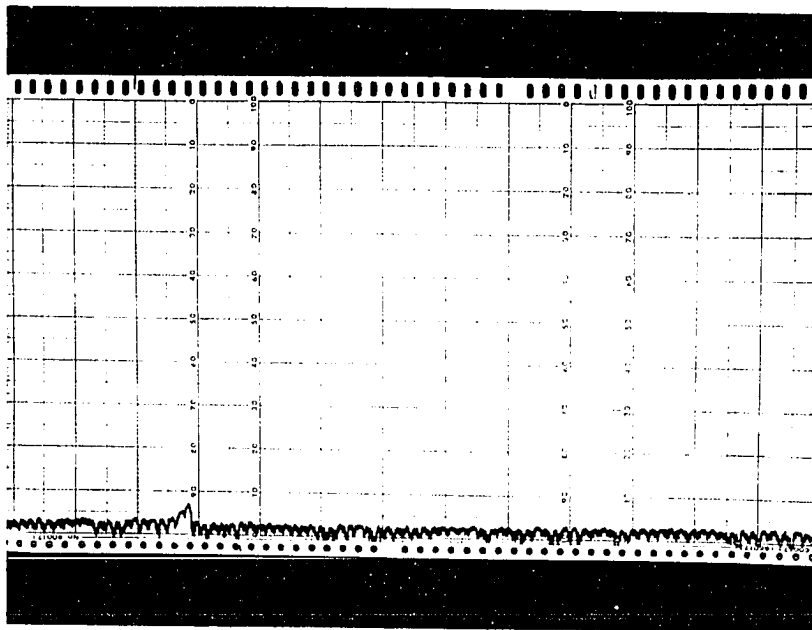


Figure 44. Baseline instability of CO₂ analyzer

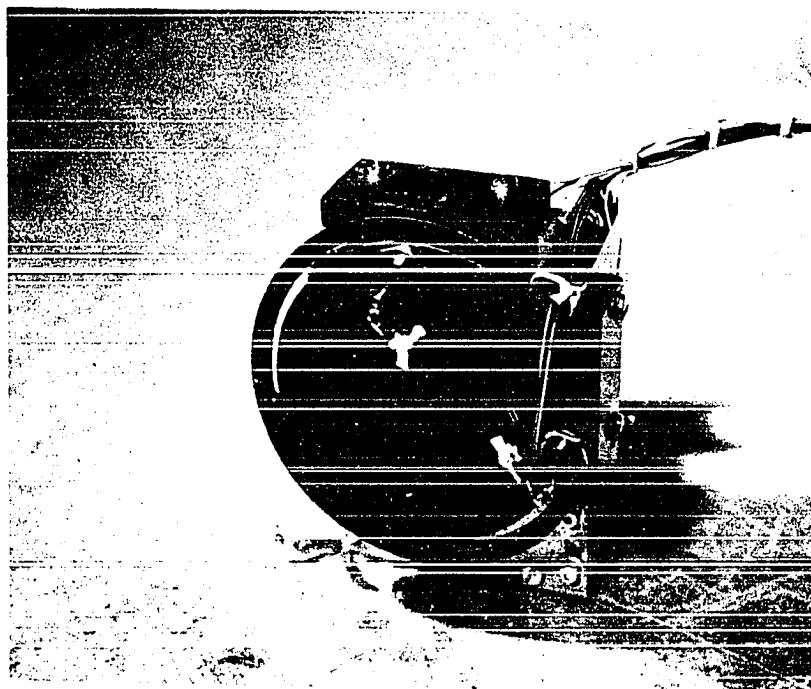


Figure 45. Solid state demodulator design for CO₂ analyzer

APPENDIX C. SUPPLEMENTARY REFERENCES BY SUBJECT

Applications of Air Ions to Medical Therapy

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APPENDIX D: ADDITIONAL DATA SOURCES FOR ION LEVELS AND MOBILITIES

Data on Air Ion LevelsIon levels in air

Yaglou et al. (1931), Wait (1931), and Nolan and Nolan (1933) have determined data for the levels and variability of the ion content of the air. Measurements on the ion content of the air have been taken at various locations by Wait and Torreson (1934), Yaglou and Benjamin (1934), Wait and Torreson (1935), Gagge and Moriyama (1935), Weiss and Steinmaurer (1937), Sherman (1940), Wait (1943), Thellier (1943), Parkinson (1948), Norinder and Siksna (1951a, 1951b), O'Donnell (1952), Norinder and Siksna (1952a), Norinder and Siksna (1953b), Gubichev (1955), Siksna and Eichmeier (1960), and Siksna and Eichmeier (1966). A great deal of variability in ion levels was generally experienced with normal levels ranging from 500-2000 ions/cc. Daily levels were generally highest shortly after noon and lowest shortly after midnight.

Ion levels from generators

Siksna and Lindsay (1959a) obtained rates of production from a tritium generator coupled directly to a measuring chamber of 2×10^9 ions/sec for a source strength of 50 mc. An equivalent basis for a 250 mc source would be a value of 10^{10} ions/sec, or a current of 0.16×10^{-8} , as compared with the value of 4.2×10^{-8} obtained in the saturation current tests of these studies.

Koller (1932) reported that the number of negative ions from the output of an ion generator was only 5.8 percent of the ions formed. This

generator used a 40-mesh grid, a 2000-volt separation potential, and an air velocity of 20 feet a second for separation.

Siksna and Lindsay (1959a) in comparing the measured ion output with theoretical values found a ratio of 1/450. This ratio is in error, however, since maximum rather than average beta energy was used in the calculations. The proper ratio should have been stated as 1/150.

Data on Air Ion Mobility

Overhauser (1949) has discussed the clustering of ions and their mobilities in relation to Blanc's law. Measurements of the mobility of air ions have been made for both natural and artificially produced air ions by Koller (1932), Siksna (1952, 1953a), Whipple (1960), and Misaki (1964). Koller found that with ions produced by a corona type generator, 69 percent of the generated ions had mobilities in excess of $0.48 \text{ cm}^2/\text{volt-sec}$. Siksna (1953b) has given the mobility spectra for ions formed by a positive corona discharge. At levels of 120,000 positive ions and 80,000 negative ions per cubic centimeter, the median mobility was $0.82 \text{ cm}^2/\text{volt-sec}$ for positive ions and $1.17 \text{ cm}^2/\text{volt-sec}$ for negative ions. Siksna found that mobilities of ions produced by corona discharge differed slightly in mobility for (+) and (-) ions. The majority of (+) ions had mobilities from $0.4\text{-}1.2 \text{ cm}^2/\text{volt-sec}$, whereas (-) ions had a majority of mobilities from $0.5\text{-}1.5 \text{ cm}^2/\text{volt-sec}$. Siksna and Lindsay (1959b) in their work found that positive ions occurred in three distinct mobility groups, 0.4, 0.8-1, and $2\text{-}2.5 \text{ cm}^2/\text{volt-sec}$. Negative ion characteristics, however, followed a continuous spectral curve. The

majority of negative ions were found to have a mobility factor, k , of 5.0-0.2 $\text{cm}^2/\text{volt-sec}$. Norinder and Siksna (1953a) have obtained typical values for the mobility of small ions at Uppsala, Sweden, during summer nights. Metnieks (1957) has described the size and mobility characteristics of air ions produced by an X-ray source. Two groups of positive ions were found. The largest, containing about two-thirds of the ions, had values of the mobility, k , from 0.6-0.9 $\text{cm}^2/\text{volt-sec}$. The remaining group had values of from 1.3 to 2.2 $\text{cm}^2/\text{volt-sec}$. Values for negative ions were from 0.9 to 1.5 $\text{cm}^2/\text{volt-sec}$ except in certain cases when values of 2.5-3.0 $\text{cm}^2/\text{volt-sec}$ were determined. Misaki found that the mobility spectrum of atmospheric ions in a semidesert area also varied with the time of day and generally followed an increasing concentration toward lower mobilities. His discussion also points out the large number of difficulties in obtaining mobility spectra measurements as does Anderson (1963). Beckett (1959, 1961) has indicated that the importance of ion mobility distribution and ion age has not been fully appreciated.

Bradbury (1932a, 1932b) determined values for mobilities of ions of several gases and gas mixtures as well as the effects of aging. The mobility of positive N_2 ions was found to be 2.09 $\text{cm}^2/\text{volt-sec}$ for ages of 0.04 to 0.5 sec. There was no noticeable decrease in mobility of the ions during this time period. Positive ions in air, however, had a lower mobility of 1.59 $\text{cm}^2/\text{volt-sec}$ for an age of 0.08 sec and the mobility decreased to 1.42 $\text{cm}^2/\text{volt-sec}$ at an age of 0.5 sec. The mobility of the H_2 positive ion with a partial pressure of NH_3 of 0.15 mm was found to be 9.4 $\text{cm}^2/\text{volt-sec}$ or substantially equal to that of the negative ion in

impure H_2 . In the case of N_2-NH_3 mixtures, a positive ion mobility of $1.83 \text{ cm}^2/\text{volt-sec}$ was observed as compared with the normal N_2 mobility of $2.09 \text{ cm}^2/\text{volt-sec}$ and no negative ions were observed.

The mobility of an ion may also be specified in terms of size and has been found to vary inversely as the square of the radius (or cross section of the particle).

APPENDIX E:

PRELIMINARY DATA FOR CO₂ OUTPUT OF CORN BORER ADULTS AND LARVAECO₂ Output of Adult Corn Borer

To establish the level and variation in CO₂ output that might be expected from the same insect over a three-day period, the CO₂ output of six individual insects was checked daily and recorded. Data from these tests are shown in Table 12.

Table 12. CO₂ output from resting female corn borers at 30°C

Age (days)	Insect						$\bar{X} \pm$ S.D.
	1	2	3	4	5	6	
	(mm ³ CO ₂ /insect/hour)						
1	81.1	80.8	84.6	87.6	75.1	65.6	79.1 \pm 7.8
2	72.8	76.1	86.9	79.2	83.1	66.9	77.5 \pm 7.2
3	71.6	66.2	87.3	83.1	77.1	64.7	75.0 \pm 9.1

These data for CO₂ output of the same individual insect over a three-day period are comparable with that obtained using different insects for each test over the same time period. An analysis of the data showed no significant difference between CO₂ output of individual insects at each age as compared with CO₂ output of the insects used in the ion tests.

CO₂ Output of Corn Borer Larvae

A brief series of tests were conducted on 5th instar larvae, with 10-minute exposures to positive air ions at levels of 5×10^5 ions/cc. The continuous activity of the larvae made the establishment of a CO₂ output level under resting conditions impossible.

For comparison purposes, average levels of CO₂ output over a six-minute period are presented in Table 13. No statistically significant change in CO₂ output caused by the positive ions was evident.

Table 13. Effect of positive ions on the CO₂ output of 5th instar corn borer larvae

Larvae no.	CO ₂ output (mm ³ /insect/hr.)		Difference $X = X_1 - X_2$	Deviation $x = X - \bar{X}$	Deviation squared x^2
	Before ions X_1	After ions X_2			
1	200.0	182.6	17.4	13.1	171.60
2	84.6	77.0	7.6	3.28	10.76
3	157.1	148.7	8.4	4.08	16.65
4	84.6	92.4	-7.8	-12.12	146.89
5	84.6	92.4	-7.8	-12.12	146.89
6	<u>132.2</u>	<u>124.1</u>	<u>8.1</u>	<u>3.78</u>	<u>14.29</u>
Total	743.1	717.2	25.9	0	507.09
Mean			$\bar{X} = 4.32$		$s^2 = 101.4$
$s_x^2 = \frac{101.4}{6} = 16.9 \quad s_x = 4.11 \quad t = \frac{4.32}{4.11} = 1.05$					

Larvae used in the tests were returned to the incubator and kept under observation following the exposure to positive ions. All pupated within the same time interval as the controls that had not been exposed to ions and emerged as normal adults. This contrasts with the reported coloration and death of fly larvae exposed to ions as reported by Chase and Wiley (1935).